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ABSTRACT

The Western Australian Science Education Association is an informal group which meets annually for a conference. This document contains the proceedings of the 1994 conference. Papers included were: (1) "Relationship Between Cognitive Style and Students' Proportional Reasoning Ability" (Ayo Akatugba); (2) "Alternative Modes of Instruction in Organic Chemistry" (George Bodner, Richard Bauer, Kirsten Lowrey & Marc Loudon); (3) "Improving Students' Imagery in Chemistry" (R. Bucat, R. Tasker, R. Sleet & W. Chia); (4) "Teaching and Assessing Tasks within the 'Design, Make, Appraise' (DMA) Strand of Technology in the Primary School" (Judith Cousins); (5) "Visualisation of Chemical Reactions Using a Multimedia Instructional Approach" (Patrick Garnett, Mark Hackling, & Ron Oliver); (6) "Profiles of Achievement in Science in Western Australian Government Schools: The Monitoring Standards in Education 1994 Report" (Ruth Hickey & Kevin Brady); (7) "A Constructivist Approach to Scientific Literacy for Technology Studies Students" (Monica Leggett & Tony Fetherston); (8) "Teaching for Understanding" (William Louden & John Wallace); (9) "Getting It To Work: Visitors' Use and Understanding of the Whispering Dishes at an Interactive Science Centre" (Terry McClafferty); (10) "Student Misconceptions of Diffusion and Osmosis" (Erica McKnight & Mark Hackling); (11) "Theory, Ethics and Politics: Interpretive Research in Science Education" (Catherine Milne & Peter Taylor); (12) "Cognitively Different? An Examination of the Thinking Levels of School Students, Trainee Teachers and Practising Teachers in Western Australia" (Gary Pears & Roy Skinner); (13) "Paying the Price for Success in Science" (Leonie Rennie); (14) "Would You Eat A Genetically Engineered Tomato? 'Public' Perceptions of Biotechnology" (Renato Schibeci, Ian Barns, Aidan Davison & Shona Kennealy); (15) "Teachers' Views About Teaching Analogies in a Systematic Manner" (David Treagust, Grady Venville & Allan Harrison); (16) "Are Students' World Views Affected by School Views: A Sociocultural Perspective" (Bruce Waldrip & Peter Taylor); and (17) "Applications of the Science Laboratory Environment Inventory (SLEI) in Singapore" (Angela Wong & Barry Fraser). (MVL)

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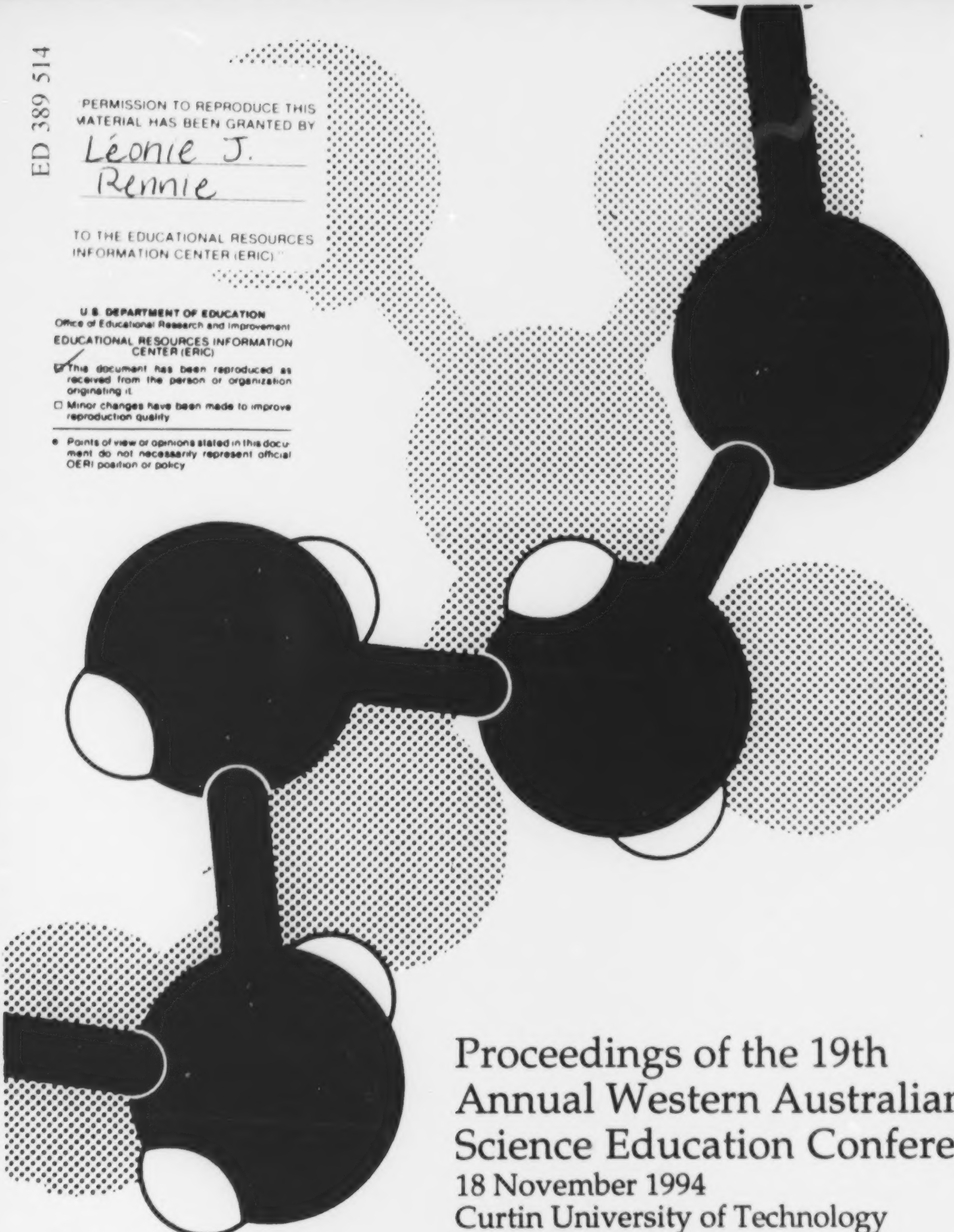

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Preface

The Western Australian Science Education Association (WASEA) is an informal group which meets annually for a conference at one of the tertiary institutions. On the two occasions when the Australian (now Australasian) Science Education Research Association met in Perth (1979 and 1991), the WASEA meeting was subsumed under ASERA. WASEA has been organised by a committee of science educators from the tertiary institutions, but several years ago elected a President (currently Léonie Rennie) and a Secretary/Treasurer (currently Mark Hackling) so as to comply with the requirements for maintaining a bank account. The conferences are still organised on a rotational basis with a good deal of collegiality.

The first meeting was held in 1975, at Churchlands College of Advanced Education, when the keynote speakers were Bob Vickery and Denis Driscoll (now deceased). In subsequent years, interstate speakers were featured, and the first proceedings, published in 1977, contained six papers and two keynote addresses from Richard Tisher and David Boud. In the past, the proceedings have been photocopied because there were no resources available for retyping papers. Last year, Renato Schibeci as Conference Organiser and hence editor of the proceedings, assembled the papers from disc, enabling a more uniform presentation. This year the papers have been edited, put into APA format and, in recognition that the assembled papers are a worthwhile resource from an active research community, an ISSN number has been assigned, and the papers made available internationally through the Educational Resource Information Centre (ERIC). Enjoy them.

Léonie Rennie
Editor

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RELATIONSHIP BETWEEN COGNITIVE STYLE AND STUDENTS' PROPORTIONAL REASONING ABILITY

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Introduction

Adolescent students seem to have difficulty understanding concepts in physics and this become more apparent during problem solving. Physics as a subject has been acknowledged by students universally to be very difficult (Easlea, 1986; Kahle, 1987; Kelly, 1981; Weinreich-Haste, 1979). Many of the concepts traditionally taught in secondary school physics are highly abstract and require students to function at the level of formal operations to attain comprehension (Herron, 1975, 1978; Krajcik & Haney, 1987; Shayer & Adey, 1982). Proportional reasoning has been identified as one of the hallmarks of the formal operational stage (Linn, 1982; Raven & Calvey, 1971). Studies have indicated that success in understanding concepts like density, concentration, force, acceleration, laws of definite and multiple proportions, speed, power, efficiency, moment and pressure which are encountered in the senior secondary school science curricula require proportional reasoning (Guckin & Morrison, 1991; Heller, Ahlgren, Post, Behr, & Lesh, 1989; Lamon, 1993; Whitmer, 1987).

Despite the importance of proportional reasoning in the learning and understanding of concepts in physics, most adolescent students seem to have difficulty solving problems that involve proportional reasoning (Hart, 1978; Karplus, Karplus, Formisano, & Paulsen, 1979; Lamon, 1993; Vergnaud, 1983). Hence there is reason to believe that some of the problems students have in learning physics concepts could be due to their difficulty with proportional reasoning (Arons, 1979; Guckin & Morrison, 1991; Linn, 1982; Whitmer, 1987). Several practical factors have been found to influence students' use of proportional reasoning in science, especially physics. Individual differences have been found to have major effects on formal reasoning (Pulos & Linn, 1981). Cognitive style has been suggested as one of the important cognitive correlates which needs to be investigated to clarify the sources of individual differences in proportional reasoning (Pulos, Karplus, & Sage, 1981). Cronbach and Snow (1977) defined cognitive style as an habitual pattern or preferred strategy of information processing. It is the unique way or manner in which an individual processes information. Students have different strategies or approaches to problem solving and they approach many if not all tasks with a set pattern or procedure (Maloney, 1983). While some of these strategies may be useful in problem solving, most of them are rather incorrect. Students probably use such strategies because they have successfully handled previously encountered situations. There are different aspects of cognitive style. This study used field dependence/independence as one indicator of cognitive style.

It has been suggested that students who are normally capable of proportional reasoning can be misled by the presence of field effects (Niaz, 1989). Field effects could be irrelevant, misleading or distracting information in a task. This study investigated the relationship between Field Dependence-Field Independence aspects of cognitive style and students' performance on physics proportional reasoning tasks. Field dependence-independence refers to extremes of the cognitive style continuum, as measured by the Group Embedded Figures Test (GEFT) (Witkin, Oltman, Raskin, & Karplus, 1971). According to Witkin, Dyk, Faterson, Goodenough, and Karplus (1962), field dependence restricts a persons' ability to disembed perceptual and conceptual patterns from the organised fields of which they are a part. A field independent person on the other hand, is one who is able to overcome misleading and distracting information and recognise significant and conceptual patterns in his environment. Field dependent students have been characterised as less analytical than their field independent counterparts, who tend to store information in a symbolic manner (Shavelson, 1971).

The purpose of this study was to examine whether or not students' cognitive styles influence their proportional reasoning ability. In order to achieve this objective and to identify how instructions can be designed to develop students' proportional reasoning skills in physics, this question was posed: *What differences exist between the proportional reasoning ability of field dependent and independent students?* The null hypothesis that there will be no significant difference between the proportional reasoning ability of field dependent students and field independent students was tested.

Method

Subjects

A total of 300 physics students from 20 randomly selected state schools in Oyo State, Nigeria, participated in this study in 1990. The subjects were Senior Secondary School (SSS) II students from co-educational schools with ages ranging between 14-18 years. Fifteen students were randomly selected in each of these schools for the study. It was expected that by this stage they would have been exposed to some considerable amount of knowledge in physics and are capable of formal reasoning as theorised by Inhelder and Piaget (1958).

Design and Procedure

A quantitative "one-shot", no control group with post-test only design was used in this study. Previous knowledge and past experiences were regarded as the treatment to which the students were exposed. This design was used because the treatment was assumed and because of the exploratory nature of the research problem which sought to establish some relationships between the variables identified in the study.

The two research instruments used for this study were the Group Embedded Figures Test (GEFT) and a developed 10-item Physics (proportional reasoning) Achievement Test (PAT) containing field effects. The GEFT has been modified and used by Oyekan (1984) in assessing the cognitive styles of students in the Nigerian environment, and was used to identify and classify students by their cognitive styles. The test was made up of 10 items which have been previously found suitable and appropriate for the Nigerian context and the cognitive level of students in SSS II. The test items were geometrical forms that might have been covered in mathematics from JSS I to SSS II, and required students to find and trace one of eight simple figures which was embedded in a more complex figure. The students were allowed two minutes for practice and ten minutes for the test. The PAT was used to obtain students scores on proportional reasoning tasks, which was used as a measure of students' proportional reasoning ability. The items consisted of four physics related Piagetian tasks adapted from the Lawson's (1978) Classroom Test of Formal Reasoning, based on the concept of volume displacement and beam balance which have been previously used by Niaz (1989) in a study similar to this. These items have been found to be fairly good indicators of proportional reasoning. The remaining six items of the test were tasks adapted from past West African School Certificate (WASC) examination multiple choice questions on different physics concepts requiring proportional reasoning.

The content validity of the GEFT and PAT were determined through a pilot study. The PAT was also examined by a physicist and a science educator to ascertain whether the expected proportions, and field effects were properly represented and correct answers were provided in the options. The reliability of the two instruments were determined by administering them to one hundred SSSII students from three secondary schools during the pilot study. The reliability coefficients for the PAT (0.77) and GEFT (0.80) were calculated using the split-half method.

The two research instruments were administered to all the students in the participating schools during normal school hours. This was carried out within a single day in each school during the final continuous assessment period of secondary schools in Nigeria. Hence the students were assumed to be psychologically ready for such an exercise. The tests were administered to the students by the researcher with the assistance of their physics teachers. The GEFT was administered first, followed by the PAT.

To test the research hypothesis, students responses on the GEFT and PAT were scored on a 0-10 scale. The corresponding z-scores of the students' raw scores on the GEFT were calculated. The students were then classified into the field dependent-independent cognitive styles using their standardised z-scores. Students who scored 0.1 standard deviation and above from the mean were classified as field independent (FI) while those who scored below 0.1 standard deviation from the mean were classified as field dependent (FD). Based on this classification, the scores of the field dependent and field independent students on the PAT were subjected to the t-test of significance.

Results and Discussion

The null hypothesis stated that "there is no significant difference between the proportional reasoning ability of field dependent students and field independent students". This was tested by compiling the scores of the field independent and field dependent students on the PAT separately. The GEFT raw-scores of the students ranged from 0 to 10 (mean = 6.44; SD = 2.09). Table 1 shows the classification of students according to their scores on the GEFT. One hundred and forty four (144) students scored from 0-6 and were classified as FD while 156 students scored from 7-10 and were classified as FI. Scores for the 300 students who sat for the physics (proportional reasoning) Achievement Test (PAT) ranged from 0 - 9 (mean = 2.82; S.D = 1.97). The relationship between field dependence/field independence and students performance on the PAT are contained in Table 2. A total number of 21 students did not respond correctly to any of the items. Three students scored 8 out of 10 marks and all three were FI. Only 2 students scored 9 out of 10 marks and both students were field independent. Table 2 shows that those who scored from 3 - 9 (150 students) were mostly FI students (64%) while those who scored from 0 - 2 (150 students) were mostly FD students (60%). Further, 63% of those whose scores ranged from 3 - 7 were field independent. No FD student scored up to 8 marks in the PAT.

The mean scores and standard deviations for FI/FD students on the PAT are contained in Table 3, and it can be seen that FI students had a higher mean score.

Table 1
Classification of Students According to Scores on the Group Embedded Figures Test (GEFT)

GEFT scores	Cognitive style	No. of students
0–6	Field dependent	144
7–10	Field independent	156

Table 2
Relationship between Field Dependence-Field Independence and Students Performance on Physics (proportional reasoning) Achievement Test (PAT)

Number of correct responses	Total	FI (n = 156)	FD (n = 144)
0	21	6 (29%)	15 (71%)
1	54	20 (37%)	34 (63%)
2	75	34 (45%)	41 (55%)
3	66	39 (59%)	27 (41%)
4	32	21 (66%)	11 (34%)
5	21	10 (48%)	11 (52%)
6	13	10 (77%)	3 (23%)
7	13	11 (85%)	2 (15%)
8	3	3 (100%)	-
9	2	2 (100%)	-
10	-	-	-

Table 3
Means and Standard Deviations for Field Independent-Field Dependent Students' proportional reasoning scores

Cognitive Style	Score (Range 0 - 10)	
	Mean	SD
Field Independent	3.32	2.00
Field Dependent	2.28	1.56

To test the hypothesis, the mean scores of FI and FD students were compared by an independent t-test. The resulting t value was 5.04, which was significant at 0.001 level of confidence. Referring again to Table 3, it is clear that the FI students' mean score was significantly higher than the FD students' mean score. Based on this result, the null hypothesis was rejected. This implies that FI students showed a better understanding of the physics proportional reasoning (PAT) tasks and hence performed better than their FD counterparts.

The results of the study suggest that field independent students are more capable of reasoning proportionally than the field dependent students when faced with proportional reasoning tasks containing field effects. This assessment agrees with the findings of Witkin et al. (1971) and Niaz (1989) that field independence correlates highly with success on proportional reasoning tasks. The field dependent students exhibited lower proportional reasoning ability. More field dependent students recorded the lowest marks in the physics (proportional reasoning) achievement test especially in those tasks involving volume-displacement and balance beam. It is possible that the inability of FD students to overcome misleading and distracting information and failure to recognise significant perceptual and conceptual patterns in the physics proportional reasoning tasks contributed to their poor performance. They could also have been misled by the presence of field effects in the physics tasks. Their high degree of field dependence seems to have restricted their ability to successfully abstract proportional reasoning patterns from the tasks. It is possible that the FD students possessed limited or no analytical problem solving strategies. These may have hindered their ability to reason proportionally. This tends to support the findings of Case (1976), who considers field dependence to be a contributing factor in students' failure to reason formally.

The general performance of the students on the PAT was poor with a mean score of 2.82. The ages of the students ranged from 14-18 years and according to Inhelder and Piaget (1958), they should be capable of proportional reasoning. Niemark (1977) suggested that "many adolescents who do not reason formally on Piagetian tasks,...do so because they are field dependent and not because they are have not developed formal operations". The results obtained in this study differed slightly in the sense that even though the students had all attained the age of formal reasoning, they did not seem to be capable of reasoning proportionally with respect to the tasks they were given. The majority of the students (82.7%) scored below 5 marks and seem not to have attained the level of formal thought. This may be hindering their learning of most concepts in physics which require proportional reasoning skills. Is it possible that 82.7% of the students could not reason proportionally? There are some who will argue that this is not possible. What then could be responsible for the generally poor performances on the proportional reasoning tasks? It is possible that some factors beside those considered in the study could be responsible for the students poor performances. It will be recalled that Inhelder and Piaget (1958) had indicated that socio-cultural factors have the potential to influence the emergence of operational reasoning ability among adolescents. Factors such as, environment, language, economic background, age, intelligence and learning may have some effects on students' proportional reasoning ability. The calculated difficulty index (31.3%) of the PAT confirmed students' difficulty with the proportional reasoning tasks. This observation is in line with the general hypothesis and suspicion that early adolescents have difficulty with tasks requiring proportional reasoning skills.

The results of this study suggest that physics teachers need to assist both field independent/dependent students to recognise proportionality and use proportional reasoning where they are required in science courses. This may help to improve their proportional reasoning ability and reduce failure rate in secondary school physics. Science teachers generally rely on proportional reasoning being taught in mathematics classroom. Physics teachers should be aware of the roles played by cognitive style in proportional reasoning and ascertain their students' cognitive styles. In addition, they should consider the extent to which the perceptual field factors can be reduced in order to enhance proportional reasoning in students (Niaz, 1989).

Since it may not be sufficient for physics teachers to simply tell their FD students about a better problem solving strategy, they may first need to convince them of the deficiencies of their present strategies before they will be willing to consider an alternative seriously (Maloney, 1983). Proportionality lessons, when provided should be tailored to the individual needs and strategies of students. As suggested by Kuchemann (1991), teachers will need to start from where the students are rather than engaging them with strategies they can hardly relate to. Most intervention programs designed so far to develop students proportional reasoning ability have been very structured and generalised, and geared towards making students become more field independent. That is being able to disembed perceptual and conceptual patterns from the organised field of which they are a part. This may not favour most disadvantaged students like the field dependent students as research has shown that students seems to show considerable resistance toward adopting formal methods for solving ratio and proportion tasks (Kuchemann, 1991). An approach that will consider and build upon individual learning strategies may lead to meaningful learning and understanding of physics concepts. This may help to produce young men and women who can think for themselves as stated in section 4: 16e of the Nigeria National Policy on Education (1981). Finally, the results of the study suggest the need for a qualitative investigation of the various factors that are influencing students' proportional reasoning ability and find out ways by which students' proportional reasoning can be improved.

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ALTERNATIVE MODES OF INSTRUCTION IN ORGANIC CHEMISTRY

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Narratives of Convictions and Constraints

Several years ago, we examined the relationship between the beliefs teachers held about the nature of science, their beliefs about how science should be taught (and learned), and their classroom practices (Brickhouse, Bodner, & Neie, 1987). We analyzed the beliefs and practices of three teachers to answer the following questions: (1) What do they believe ought to be done to teach science effectively?, (2) What instruction do they carry out in the classroom?, and (3) What constraints provide barriers to the implementation of instruction consistent with their beliefs about what they ought to do to teach science effectively?

One of the teachers had more than 20 years of experience, and, not surprisingly, exhibited class-room practices that were highly congruent with his beliefs about both the nature of science and the way science should be taught. Another, with 13 years of experience, had developed a framework for instruction that was consistent with her philosophy of science *but diametrically opposed to the one she used when she first began teaching*. At this point in their careers, both teachers operated from a consistent, self-reinforcing belief system (Hollon & Anderson, 1987). Their classroom instruction was remarkably consistent from one day to the next, and they expressed personal philosophies that were congruent with their actions in the classroom.

The third teacher was a second-year middle-school science teacher (Brickhouse & Bodner, 1992). Data from his classroom were difficult to analyze because the classroom instruction was variable and couldn't be predicted from interview data. It was only by asking concrete questions about his rationale after observing his instruction that we were able to separate what he believed was desirable from what he found possible.

Common themes in the second-year teacher's discussion of what science teaching *should be* include: "getting dirty," "messing around," and "going off on tangents." In spite of this, the majority of the time in his class involved whole-class discussions that closely followed the organization of the book and emphasized learning terms. Although he believed that science is a creative, anarchistic endeavor, and science teaching should ideally occur in an informal environment, he also believed that students need to be given a firm foundation of knowledge from which they can build. Although he viewed science as an endeavor practiced by creative, purely-motivated individuals, the presentation of science in his classroom took on a formal and structured image.

The classroom practices of the beginning teacher reflected the struggle he faced to reconcile conflicting beliefs about what is desirable, as well as conflicts between what he wanted to achieve and what he felt was possible within the constraints of his preparation and the institution in which he worked. Our mid-career teacher reflected on having gone through a similar process. She commented that she was very unhappy during her first five years as a teacher, and thought about leaving the profession until she developed a very different approach to teaching her content area – physics.

The early years of both our mid-career teacher and our beginning teacher were characterized by conflict between their perceptions of what science is and what it means to teach science.

Proceedings of the 19th Annual Conference of the Western Australian Science Education Association, Perth, November, 1994.

The Organic Chemistry Classroom

Organic chemistry is a sophomore-level course for students majoring in chemistry, chemical engineering, materials science, biology, medicinal chemistry or pharmacology, and students who describe themselves as "pre-med," pre-dent," or "pre-vet." It is a required course for virtually every student who takes it – it is rare to find someone who takes organic chemistry as an elective. It is perceived by students as a difficult, threatening course, which controls their future. (Pre-med students, for example, know that they won't be admitted to medical school if they do less than B-level work and believe that anything less than A-level work will significantly diminish their chance of being admitted.)

The typical organic textbook contains 1200 pages, and most organic chemistry instructors try to cover the entire text. The level of mastery expected of students can be appreciated by considering a few questions from the first-half of a typical text (Solomons, 1992).

> Although ethyl bromide and isobutyl bromide are both primary halides, ethyl bromide undergoes SN2 reactions more than 10 times faster than isobutyl bromide. When each compound is treated with a strong base/nucleophile (CH3CH2O-), isobutyl bromide gives a greater yield of elimination products than substitution products, whereas with ethyl bromide this behavior is reversed. What factor accounts for these results?
>
> When 2-methyl-1,3-butadiene (isoprene) undergoes a 1,4 addition of hydrogen chloride, the major product that is formed is 1-chloro-3-methyl-2-butene. Little or no 1-chloro-2-methyl-2-butene is formed. How can you explain this?

Organic chemistry is invariably taught by a content-specialist. Not just a chemist, but an organic chemist. It is taught from the lecture format, with little if any interaction between the instructor and the students. No questions, other than rhetorical questions, are asked, and few, if any, questions are elicited from the students or answered when asked unelicited.

Students often believe that the key to organic chemistry is memorizing as much information as possible, and blame their failure in the course, to their inability to memorize information.[1]

The Subject of This Experiment

G. Marc Loudon is a professor and Associate Dean for Research in the School of Pharmacy at Purdue University. He is a dedicated instructor, who has taught organic chemistry to students in pharmacy for more than 20 years. He is the author of a textbook in organic chemistry (Loudon, 1988) and has received recognition for his teaching at the departmental, school, and university level.

Marc exhibits the hallmarks of a superb lecturer. He is organized, insightful, clear in his presentation of material, and his students perceive that he is sincerely interested in them and that he wants to help them succeed. Regardless of whether you asked students, faculty, or administrators in the School of Pharmacy, Marc would be described as an exemplary teacher (Gallagher & Tobin, 1987).

The Connection

The reader might be tempted to ask: What is the relationship between Loudon's organic course and our work on beginning teachers? Let me propose the following connections between these seemingly disparate situations.

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[1] Failure is defined as a grade significantly lower than expected/desired. For some students, a C or even a B represents failure. Students therefore often take the course over and over again. The first author remembers a student who took seven semesters to complete the two-semester course.

- Like the beginning teachers in our other study, Loudon recognized conflicts between his beliefs about the nature of science and his belief that students' success in his class-room depended on his ability to present a formal structure of organic chemistry for his students to learn.
- Like the other teachers, Loudon recognized the inconsistency between many of his beliefs about the nature of science (and the process by which it is learned) and his practices in the classroom.
- Although he was a dedicated instructor, the three hours each week that he spent in the classroom was only a fraction of Loudon's professional time. He was also a researcher, administrator, author, and mentor of students doing research in medicinal chemistry. Because the practices he used in mentoring research students were highly congruent with his views about the nature of science and how it should be taught, Loudon was able to live with the conflict between his beliefs and practices in the formal classroom far longer than the teachers in our earlier study.
- All three teachers began their career using practices that were governed by the personal, bureaucratic, and technical constraints they faced (Edwards, 1979; Zeichner, Tabachnik, & Densmore, 1987).

Loudon's practices in the formal classroom were the logical consequences of the constraints he faced. Within the context of personal constraints, Loudon's approach to the undergraduate course reflected his own experiences as a student and the monolithic agreement among organic chemists about the way the course should (or must) be taught.

Bureaucratic constraints took several forms. First, and foremost, was the fact that he wasn't in sole control of the course. He taught one semester of a year-long course, and therefore faced constraints placed on him by his colleagues to cover enough of the textbook to prepare the students for the second-half of the course. He also recognized the role that his course played in providing the foundation upon which most if not all of the later courses in pharmacy built. Thus, it isn't surprising that for him, the textbook *was* the curriculum.

Technical constraints are often the most pervasive because they are unquestionable forms of control. Loudon's course was restricted to an environment in which there were three lectures per week, of 50-minute duration, that were scheduled for 7:30 AM, in a lecture hall that held slightly more than 200 students. He was expected to give hour exams, and use these exams as the primary form of both student assessment and evaluation of his performance. He faced the prospect of teaching at least 170 students – the sophomore population in the pharmacy program – or more, if students who wished to be admitted to pharmacy enrolled in his course.

The Search for Alternatives

Conversations with colleagues in other departments, coupled with his own sense of dissatisfaction with his performance in the classroom[2] led Marc to implement a course last Fall in which he made the following changes.

- Students would be encouraged to work together in groups of three outside of the classroom.
- To convince them that working in small groups would be useful, students would be encouraged to work together in their groups during "lecture."
- The amount of time devoted to a whole-class lecture format would be minimized.
- The class would be as interactive as possible. It would begin in a teacher-centered format, in which the instructor presented the topic to be discussed, but the discussion would be allowed to drift as the students deemed necessary.
- To consolidate the gains of working in small groups, the students would be allowed to start the examination process in groups of three. The students would be given the exam, allowed to discuss it within their groups for 30-45 minutes, and then asked to answer the exam questions individually.

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[2] It should be noted that the only individual who was dissatisfied with Marc's performance was himself.

- Students who felt threatened by this format would be allowed to switch into another section that was taught by a strictly lecture-oriented format.

The Experiment

Two graduate students in chemical education were assigned to work with Marc Loudon during the course of the semester. One was a Ph.D. student whose primary focus was the students, and who collected in-depth interviews about their perceptions of organic chemistry and the format in which this course was taught. The other was an M.S. student who focused on the behavior of the instructor. Methodology therefore included both qualitative (Erickson, 1986; Lincoln & Guba, 1985) and hermeneutic techniques (Guba & Lincoln, 1989) within the framework of action research (Hopkins, 1985; Kemmis & McTaggart, 1990a; Kemmis & McTaggert, 1990b).

Although they had no effect on his behavior (Cooney, 1985; Zeichner, Tabachnik, & Densmore, 1987), students' reactions to the format of instruction contributed extensively to the instructor's feelings of stress at the beginning of the experiment. Excerpts from two e-mail messages received within the first week of the semester are given below.[3]

> One of our students ... – unfortunately, an "A" student in general chemistry – called me this morning in a state of high stress saying she wanted to transfer out of our section. Her reason is that "she doesn't like the group study format." I asked her how she planned to handle the group-study format in all her Pharmacy Practice classes, and she said that she will deal with that, but that "organic chemistry is too important and she is too scared of the class to have to rely on others." Although I was sympathetic to her privately, I'll tell you that I believe this attitude is very typical of some of our students with better grades. [24 Aug 93 08:39:03]

> I think we have a phenomenon on our hands. Two other students, all straight-A students (like the last one), are thinking about changing sections. I've jawboned one of them ... nothing definite yet. All three are relatively introverted ... all seem intimidated by the "open" format of the class. All are female (although this may be a coincidence, since the class is 70% female anyway). My emotional reaction is to be irritated ... my more rational response is now to be genuinely intrigued. [26 Aug 93 15:37:13]

The research team was delighted to hear, roughly half-way through the semester, that the first of these students asked the instructor of the lecture section, into which she had switched, if he would organize groups of students who could study together outside of class.

Impact on the Classroom Environment

With rare exception, Loudon was able to transform the classroom environment into one that was interactive. Part of his success might be the "bag of tricks" he had developed over the years to explain phenomena with which students have historically had difficulty. Instead of delivering these explanations in a lecture format, he used them in response to either a question from a student or his perception of difficulties students were having as a result of the on-going, real-time interactions he was having with the students in the classroom. Consider the following example from a discussion of resonance hybrids, for which the key concept is the fact that we use two (or more) imaginary resonance structures to describe a real molecule that is an average or hybrid of the imaginary resonance structures.

L: Think about resonance structure this way. Think about like, um, a detective. Think about Sherlock Holmes, okay? And think about James Bond. What's true about James Bond and Sherlock Holmes? What do they have in common?

S: Both English (Students laugh)

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[3] The class met for the first time on 22 August 1993.

L: What else do they have in common? ... They are both fictional. They both never existed, okay? But when I say Sherlock Holmes a definite image comes to your mind, right? A guy with a pipe, plays the violin, you know, uses coke maybe. Okay? And, and James Bond the guy who catches the bad guy, never gets his suit rumpled, uh, you know (Students interject but inaudible). If I say that there's a real person, a detective, Joe Smith, okay, and he's (writes on the board)

[James Bond ↔ Sherlock Holmes]

Does that mean that he has a split personality, that he's James one part of the time and Sherlock Holmes part of the time? (Students laugh) No. One person, okay. Describe Joe Smith.

S: He has, I don't know, a mixture of both. A womanizer that smokes a pipe (Students laugh).

L: Yeh. A womanizer that smokes a pipe. He's got the idea. These are fictitious entities (referring to the resonance structures). This structure does not exist. This structure does not exist. But we use them as convenient fictions together to describe a structure that does exist. That's what resonance structures are. Any questions about that?

The Inevitable Question

Whenever interactive modes of instruction are described to chemists, someone in the audience asks: "But how will I find time to cover all of the material?" At various times during the semester, the instructor exhibited feelings of uncertainty about whether he was covering enough material. During his discussion of nuclear magnetic resonance (NMR) spectroscopy, for example, Marc complained that he normally got through between 6 and 10 sample problems, but this time, the entire class period was devoted to a single problem. He was therefore both surprised and delighted to find that, as he described it, this class "blew away" the questions on NMR. (They did far better than any previous class.)

On-Going Data Analysis

We are still in the preliminary stages of analyzing the voluminous data collected in this experiment. We are beginning to understand the factors that motivated Marc to look for an alternative mode of instruction in his classroom and the constraints he faced (and still faces) trying to implement the alternative mode he found. As might be expected from a project whose theoretical basis was action research, we are going back into the classroom next Fall to change what is done to both encourage and facilitate group learning in this environment.

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IMPROVING STUDENTS' IMAGERY IN CHEMISTRY

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Introduction

The last 15 years has seen the accumulation of a mass of research evidence concerning the inadequate understanding of chemistry which has been diagnosed in students at both the secondary and tertiary levels of education. Many of these findings have been remarkably consistent from country to country. Nakleh (1992) has published a review of investigations into student misconceptions in a range of areas of chemistry.

Many of the findings of poor chemical understanding can be traced to either inadequate student imagery of matter and processes at the sub-microscopic level of atoms, molecules and ions, or to poor ability to interpret chemists' representational language of symbols, formulas and equations. Evidence for the former is apparent from the following list of examples of misconceptions that have been diagnosed in relation to the nature of the three states of matter, and transitions between them.

- Matter is continuous. Students have difficulty imagining empty space between particles (Andersson, 1990).
- Atoms and molecules have the same macroscopic properties as the substances that they constitute (Andersson, 1990).
- There are considerable spaces between molecules in a liquid (Hill, 1988).
- There is little difference between the densities of the liquid and gaseous states of a substance (Hill, 1988).
- Water molecules within a phase may have different sizes (Griffiths & Preston, 1992).
- The size of a water molecule depends on which phase it is in (Griffiths & Preston, 1992).
- Bubbles in boiling water are made up of "heat" or "air" or "oxygen and hydrogen" (Osborne & Cosgrove, 1983, Bodner, 1991).
- Melting and boiling of molecular compounds are processes in which covalent bonds within molecules are broken (Sleet, 1993).

In addition, Ben-Zvi, Eylon and Silberstein (1987) have shown that many students in their study have poor imagery at the particulate level of the dynamic and mechanistic facets of chemical change. Kleinman, Griffin and Konigsberg (1987) found evidence of the importance of images to experienced chemists and showed that professional chemists used more abstract imagery than students. They conclude that "classroom instructional methods should consider that the ability of a student to understand chemistry may be related to the student's ability to develop specific images appropriate to the chemical concepts."

These findings are consistent with the views of Johnstone (1991) who pointed to the difficulty that students experience as they are required, often without realising it, to flit between a tangible and visible macrophenomenon (eg., *Salt dissolves in water*), sub-micro images which constitute rationalisations of the observable behaviour (*Ions in a regular lattice are attracted to water molecules and towed off into solution*), and symbolic representation of the phenomenon (the chemical equation).

Proceedings of the 19th Annual Conference of the Western Australian Science Education Association, Perth, November, 1994.

Ben-Zvi et al. (1987) distinguish between two levels of sub-microscopic imagery. They point out that we sometimes use single-particle models, such as a single molecule of water, when we wish to talk about bond angles, polarity and symmetry. On the other hand we sometimes use multi-particle models, such as a kinetic molecular image of water vapour, when we rationalise bulk properties. Ben-Zvi found that incorrect responses to questions about chemical change could be attributed to the fact that the students used a single-particle *image, rather than a multi-particle image, to interpret symbolism such as* $O_2(g)$.

Both Ben-Zvi et al. (1987) and Hill (1988) draw attention to the likelihood that many textbook diagrams can induce incorrect mental images, giving rise to misconceptions. Textbook diagrams representing various states of matter commonly show static particles and grossly misrepresent the number of particles in a vessel, as well as the spacings between particles in relation to their sizes. Chemical change is often misrepresented by diagrams that show one molecule of each reactant.

The VisChem Project

The work reported in this paper is directed at bridging courses for students with weak chemistry background enrolling in first-year university chemistry, but has applications in both school chemistry classes and undergraduate mainstream chemistry courses. It is motivated by the conviction that students' imagery is an important determinant of chemical understanding, and that this relationship has received less attention than it deserves by teachers at all levels. The authors also believe that the commonly available sources of students' images are, in many cases, less than helpful.

A series of computer-generated three-dimensional animations of the three phases of water, as well as transformations between those states, has been designed and developed. The objective was to create animations that represented as closely as possible the images that professional chemists have of these substances and phenomena. Accordingly, the task has involved the collaborative inputs of chemists, graphic artists and computer programmers.

There are several possible modes of use of these animations, which are stored as Quicktime movie clips on Macintosh computers. For example, each animation clip can be called up for projection during classroom discussions, in any sequence and combination that seems appropriate to the teacher. Eventually, the full set of animations will be used in the production of a computer-based learning programme. This paper particularly concerns a "stand alone" video presentation that has been compiled from the animations in a fixed sequence that has been designed to constitute a coherent story, in conjunction with voice-over and sound effects. Originally intended as a vehicle for demonstrating the quality of the animations, it has been increasingly recognised that the video has potential as a teaching tool, if only because of its convenience of use.

The video, which runs for ten minutes, has been designed with the specific intention of linking the macro phenomena and their sub-microscopic representations. For each state of water or transformation between states, there is a transition from a video shot of the macro phenomenon to the computer-generated sub-microscopic animation at the molecular level. In each case, the transition is made with a considerable zooming effect so that the viewer experiences a sense of entering into the substance(s) at the molecular level. The video has been entitled *Water: A molecular substance. Let's look into it.*

Nature of the Animations

It was intended that the animations would resemble the mental images that professional chemists have, even though it is recognised that there will not be a unique mental representation among chemists of any of the states of water or the transformations between them. In general, the animations use "space-filling" representations of molecules and attempt to give appropriate senses of dynamism and degree of crowding.

The major objective of the authors is that students who see the animations will develop long-lasting images that are at least consistent with the scientifically accepted models of matter, and which do not include the common misconceptions that have been diagnosed in research investigations. Accordingly, it was important to define the key features of the images that were regarded as desirable, and therefore, the key features of the animations created. These are listed here:

Solid phase (ice)
- Comprised of discrete H_2O molecules.
- Regular structure with H_2O molecules having "fixed" positions except for vibrations about those positions.
- H_2O molecules have vibrational kinetic energy, but not translational kinetic energy.

Liquid phase
- Comprised of discrete H_2O molecules.
- Less ordered state than the solid, but the H_2O molecules are still crowded closely together.
- H_2O molecules have translational kinetic energy as well as vibrational kinetic energy.

Vapour phase
- Comprised of discrete H_2O molecules.
- Mainly empty space.
- Rapid random motion of H_2O molecules in straight lines except when path is changed by collisions.
- Molecules have vibrational, rotational and translational kinetic energies.

Melting
- Discrete H_2O molecules in both solid and liquid phases.
- Size of H_2O molecules is the same in both phases.
- Vibrations of H_2O molecules increase as temperature is increased from below the melting point.

Boiling
- Boiling occurs when many bubbles form in water and rush to the surface of the liquid.
- Bubbles in boiling water contain H_2O molecules.
- The size of the H_2O molecules is the same in both the liquid and vapour phases.

Evaporation
- Localised crescendo of activity near liquid surface gives rise to a H_2O molecule with high energy escaping into the vapour phase.
- More H_2O molecules escaping from the liquid than returning to it from the vapour phase.
- The attraction between the H_2O molecules in liquid water prevents the less energetic molecules from escaping into the vapour phase.

The animations are consistent with currently acceptable scientific views, but do not attempt to teach by comparison of these views with particular misconceptions. For example, in the animations of the processes of melting and boiling, the H_2O molecules retain their identity. No attempt is made to indicate that covalent bonds are not broken during these processes. Teachers may, however, decide to superimpose this negative message over the showing of the animations.

Design Issues Involving Chemistry

Very early in this work, the authors recognised the distinction between animations which are exact reproductions of "reality" and animations which create acceptable impressions. For example, an animation that showed H_2O molecules in the vapour phase moving at 150 ms^{-1} across the screen would not be sensible. This leaves developers with a decision that involves chemical licence: How fast should the "molecules" move across the screen so that the impression created is acceptable? Similar decisions involving chemical licence relate to all of the following: vibrational frequencies in ice; the degree of crowdedness of H_2O molecules in liquid water; how rapidly H_2O molecules "diffuse" across the screen in liquid water; how many molecules should be shown on the screen in representations of the vapour state; how frequently molecules should be seen to collide in the vapour state.

Even more basic decisions include whether molecules should be represented as being coloured. What colours? Should the hydrogen atoms and oxygen atoms in water molecules be differently coloured? Should a crashing sound effect be used at the instant of molecular collisions?

To foreshadow the problems of other animations beyond those representing the states of water and transitions between the states, one is faced with decisions such as whether to accurately represent the relative concentrations of solute and solvent particles in 0.1 M salt solution. How does one represent initiation of precipitation growth? How should metallic sodium, with its "sea of electrons" be represented? If we use the typical textbook representation of metallic sodium, how do we portray the transfer of two electrons to a chlorine molecule during the reaction between sodium and chlorine?

All designers of computer imagery will be faced with issues that need to forsake scientific correctness of the animation in the interests of (i) clarity of the representation, and (ii) quality of the resultant visual impression that remains with the student.

Ongoing Productions

The VisChem team are currently engaged in extending the repertoire of three-dimensional computer-based animations to physical processes such as dissolving and precipitation, as well as to chemical reactions such as acid-base reactions and oxidation-reduction reactions. Each of these present their own particular difficulties, but the authors remain convinced that this is one area where the computer has an advantage over the two-dimensional, static constraints of diagrams in textbooks and on chalkboards.

Evaluation

An Australia-wide evaluation of the animations, as presented on the videotape, has been conducted. Teachers in about 25 classes have responded to a questionnaire concerning their impressions of the animations, and their students have provided pre-test/post-test evidence of learning outcomes arising from watching and discussing the video. Analysis of the evaluation data has not been completed.

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TEACHING AND ASSESSING TASKS WITHIN THE 'DESIGN, MAKE, APPRAISE' (DMA) STRAND OF TECHNOLOGY IN THE PRIMARY SCHOOL

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Introduction

The focus on technology in the primary school curriculum is a recent one. Researchers such as Skamp (1986) Genoni (1988), and Fitzgerald, Fagone, Ritter and Beechy (1989) all stressed that children need to become technologically aware. The Science Education Focus Group (1991) concluded that "science and technology for all must become a reality, not just a catch-phrase." The result has been the Australian Education Council declaring technology as having 'broad area of learning' status' thus ensuring that it will become a subject in its own right. Although some States and Territories have opted to develop their own Profiles and Statements in technology, these have many similarities with the National material in that they contain matching strands and bands. In Western Australia the Statement and Profiles are titled *Technology and Enterprise*. Within this statement four interdependent strands are shown and these are perceived as providing a framework for planning technology programmes in schools and for assessing student learning. The strand of 'designing, making and appraising' (DMA) links with the other three strands through the overarching features of investigation, decision-making, problem-solving and evaluation.

The problems teachers have faced in teaching primary science have been well documented. Classroom management difficulties and lack of resources have been highlighted by Yates and Goodrum (1990), Aubusson and Webb (1992), Goodrum, Cousins and Kinnear (1992) and Henderson (1992). Low teacher confidence due to perceived lack of science background knowledge has also received considerable attention from researchers: Speedy, Annice and Fensham (1989); Jeans and Farnsworth (1992) and Tasker (1993). The teaching of technology in primary schools may follow a similar path to that of primary science and little may be achieved if teachers are not given assistance with the implementation of technology programmes and the provision of effective assessment strategies so they can best structure technology lessons to promote student learning.

Two further issues are also relevant to this study. Firstly, there is increasing recognition of the importance of individual differences in learning situations and a demand to provide education designed to meet the needs of all students. This emphasis on individual student needs has resulted in teachers being required to assess student development in many areas and has led to a "reduction in formal testing and an increase in the use of profiling" (Francis, Hill & Hingston, 1992, p. 14). Thinking and problem-solving skills, as well as knowledge, must now be assessed. Student evaluation is expected to be used not so much for summative assessment, which provides overall evidence of achievement, but rather as formative assessment used by teachers in deciding how a student's learning should be taken forward. Assessment in the technology learning area has been taken into account by including how to evaluate technology tasks effectively as an aspect of this study.

Secondly, the issue of gender, relative to teaching and assessing technology tasks has been addressed. The fact of girls being disadvantaged in science teaching and assessment has been thoroughly researched (Kahle & Lakes, 1983; Whyte, 1986; Rennie, Parker & Hutchinson, 1985), and continued vigilance must be maintained with technology to ensure girls are not also disadvantaged in this area. Hildebrand (1989) has pointed out the need for women and girls to feel more in control of the science and technology in their daily lives and that a single teacher can have an impact on an individual's understanding and empathy for science. Kelly (1985) has discussed the gender bias in science and technology resource material and Rennie and Mottier (1989) have also stressed the importance of gender-inclusive resources being used to make students see science and technology as human activities. Whyte (1986) noted that girls have fewer opportunities to develop practical and technical skills while Stokes (1989) observed that girls were often less adept than boys at construction activities. Research in technology education in the primary classroom should consider the gender perspective in order to determine whether there is cause for concern in this area and if so to assist teachers to develop more gender-inclusive classroom practices. The research questions for this study take into account the issues outlined.

Research Questions and Aims

- What strategies will be most suited to enhancing student involvement and learning in technology tasks?
- How do children perform when engaged in DMA tasks?
- Which dimensions of capability on DMA tasks can be readily assessed?
- How can the information gained through observing students engaged in DMA tasks be used to assist teachers in implementing such activities in the classroom?

This paper is a description of a study carried out with two small groups of upper primary children engaged in a set technology task. The aim was to focus on the classroom implementation aspects of a technological task within the DMA strand and to observe the different approaches adopted by boys and girls. Consideration was given to how primary children investigate issues, generate designs, plan and carry out production processes and evaluate products. The DMA task was to build a bridge to satisfy set criteria, that is, it had to span a certain width and support the weight of two toy cars.

Methodology

Eight Year Six (10/11 years of age) children from a local primary school were chosen by the class teacher to take part in the technology task. There were four boys and four girls. The children were of average ability and selected by the teacher because they were not involved in any other 'special' programme within the school. These children were taught science once a week (by another teacher) but they had not had any lessons in technology as a separate subject. This group was designated Group One.

A second group of Year 6 children, from the same school, but from a another class, undertook an identical technology task. The difference between the two groups was that Group 2 had been taught a four lesson science sequence on the topic *Structures* by the class teacher prior to attempting the technology task. This lesson series focused on the strength of structures and the children had experimented on how to give a structure greater stability. This group comprised seven boys and one girl. These children came from a grouped Year 5/6 class and this was the complete Year 6 cohort. The two groups were completely comparable except Group 2 had recently completed the four science lessons on the strength of structures.

The children were brought to the University for three 'technology task' sessions, each of one and a quarter hours duration. The children carried out the activities in the science laboratory. As they had been in the laboratory on other occasions for science lessons they were familiar with the surroundings.

Session 1 involved pairing the children, a general discussion on what they thought technology was, setting the technology task, and commencing the design. They were shown the materials that would be available for the model (cardboard, string, straws, glue etc.) and asked to complete a list of needed materials. Session 2 comprised completion of the design and commencement of making the model. Session 3 involved completion of the model and appraisal.

During each of the three sessions the children were video-taped as they worked, audio tapes were positioned by each pair and a research assistant observed the group using a prepared observation instrument. The children were eager to be part of the exercise and were happy to interact with the researcher and other group members.

Results

Session 1 with both groups was very successful. The children's responses to 'what is technology' were varied and included, 'machines, computers, weapons, inventions and special effects.' They listened attentively as the task was explained to them and were eager to commence the design. They were shown the materials that would be available for building the model (cardboard, string, straws, glue etc.) and they made careful lists of what would be needed to build their design. Overall they were all responsive, interested and worked quite diligently. Each pair produced a design, though some designs were not quite complete.

Session 2 was less successful. The children seemed quite excited and noisy (particularly the boys). The materials they had ordered were waiting for each pair and they were directed to commence their model. At the end of this session little had actually been accomplished by any of the pairs except for Pair 3 Group 2 who had worked well and nearly completed their bridge.

Session 3 was a hive of activity. The children were told the model had to be finished and tested and they were shown the testing apparatus – a tank. This resulted in an urge to complete the 'making' aspect so they could test their models in the tank. Half-finished models were tested several times and then rapid adjustments made. Pairs 3 and 4 of Group 1 (pairs of girls) carefully continued with the building of their models, sharing tools and materials, discussing ideas and generally being very cooperative. The final part of this session involved each pair reporting to the others and then testing their model. They came to the front, showed their design and model then placed it in the testing position. Each pair was then given a model from another pair and they evaluated that model by using a 'Test Sheet'.

Assessment of the three aspects 'design, make, appraise'.

Design

Group 1.

Pair 1 (boys): a clear drawing with little resemblance to a bridge. Completely drawn by Boy A with little input by Boy B.

Pair 2. (boys): a clear diagram that looked like a chair lift. Major input by Boy C but agreement and suggestions from Boy D.

Pair 3 and Pair 4. (girls) Designs were more 'pictures'. They contained a scene, not just a bridge.

Group 2.

Pair 1 began drawing triangular shapes (which appeared to relate to their previous science work in structures) however, when they looked across at what others were doing they had long discussions about whether to go on with this. They did a basic design.

Pair 2 did two simple designs, the first with no support the second with some pylons shown.

Pair 3 were cooperative and shared ideas and produced a design that gave evidence of some perspective.

Pair 4 drew several very rough designs that did not really give much of an idea of what they were going to build.

Make

Group 1.

Pair 1 actually built a boat not a bridge. The suggestion was that the cargo would be placed on board and then the 'raft' blown across. This model was a failure and sank immediately.

Pair 2 built a type of chair lift with no stable side supports. The containers could not hold the cargo and it collapsed immediately.

Pair 3 built a bridge-like structure which was quite stable in the centre but the side supports were weak and it fell in.

Pair 4 built a flat strong structure which rested on the 'island' on one side and the 'mainland' on the other and supported the cargo well.

Group 2.

Pair 1 did not build a very successful bridge. The six pylons were weak and joined the top (just a piece of cardex) using masking tape. The bridge did not support the cars.

Pair 2 made a similar structure but use more pylons which they poked through holes made using a punch. They also reinforced the top with extra cardex.

Pair 3 attached groups of pylons (into which they had inserted pipe cleaners for greater strength) using glue. They also stuck matches across the top of the bridge as 'road humps'.

Pair 4 had little success. They could not agree on what to do and their ideas often did not work and they spent a lot of time trying to 'patch up' the model. They did decide on a curved road surface to keep the cars on the top.

Appraise

Group 1

Pair 1, Boy A, carried the model to the tank and carried out the test. Boy B just watched. "This doesn't work,' said Boy A. Boy B said, "I knew it wouldn't". Boy A rushed back to the desk and began trying to build another model.

Pair 2 both held the structure in position and then tried to load on the cargo. "It's not strong enough and if we let go it will crash", said Boy C. "Yes, all the weight is on one side" said Boy D.

Pair 3 both held the ends of the bridge thus making it stable. "If we let go it will fall in" said Girl A. "Yes, we should have made stronger end bits" said Girl B.

Pair 4 walked together to the test tank both carrying the bridge and laid it across the 'ocean'. They looked at each and smiled. "That's O. K." said Girl C. "The girls' bridges were the best" said Boy A.

Group 2

Pair 1 tested their bridge and it immediately fell over. "We need more pylons", one said, and they tried to add more but even on the second attempt it had to be supported by hand.

Pair 2 tested their bridge several times but admitted the joinings didn't really work.

Pair 3 set theirs up and it was successful. They watched the other pairs carefully and pointed out faults with each.

Pair 4 only managed to finish in time for one test which was unsuccessful. The girl blamed the boy and kept saying. "You should have done it my way" – though in actual fact they had worked to her plan.

Conclusion

This study has highlighted some of the difficulties in the successful implementation of 'design, make, appraise' technology tasks with primary children and raises more questions than it answers. The design phase contains aspects of visual art which may have to be considered by the teacher. Will children require lessons in 'design'? Work by Fleer (1992) showed that even quite young children can develop their skills of representation. Matching imaginative abilities with representational skill may be an area in which teachers need to have realistic expectations of what can be achieved. Stressing the purpose of designs as well as developing design drawing skills may need to become a focus for teachers.

Should technology construction activities (the 'make' phase) be the conclusion to work in science, to allow for application of knowledge gained (though there appeared little carry over of knowledge with Group 2 in this study) or should children be encouraged to try their ideas freely without the constraints of specific previous experience? Teachers may need to plan for both situations to be explored.

How can children be encouraged to see the value of appraisal? If appraisal is seen to mean always having to improve the final product it may be viewed by children as 'more work.' The skill of appraisal will need to be developed in a 'real-world' context to give it meaning and children will need to be taught appraisal skills.

The understandings teachers have of technology and their expectations of children's capability in this area, plus their pedagogical practices will all significantly impinge on the teaching of this new 'broad area of learning' in the primary school.

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VISUALISATION OF CHEMICAL REACTIONS USING A MULTIMEDIA INSTRUCTIONAL APPROACH

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Introduction

In common with other science disciplines the research literature in chemistry education includes numerous studies which have investigated students' understandings of chemistry concepts (for a review see Garnett, Garnett & Hackling, 1994; or Nakhleh, 1992). These studies indicate that students often develop understandings of chemical phenomena which differ from the 'accepted' scientific view and that the misconceptions or alternative frameworks they hold are resistant to change. The origins of specific commonly held misconceptions may be numerous and include factors such as the use of everyday language in a scientific context; the oversimplification of concepts and use of unqualified generalised statements; the use of multiple definitions and models; the rote application of concepts and algorithms without understanding; students' preconceptions from prior world experiences; overlapping similar concepts; and inadequate prerequisite knowledge.

In addition to these factors, students' understanding of many chemistry concepts and associated phenomena depends on their ability to visualise the submicroscopic particulate nature of matter and the processes involved in physical and chemical change. It seems likely that a major barrier to students developing a scientifically valid understanding of many chemistry concepts is their inability to visualise on a particulate/molecular/atomic level the nature of matter and the physical and chemical processes it undergoes.

The nature of matter

Student understandings of the particulate nature of matter has been the focus of numerous studies at a variety of levels. Some of the documented misconceptions (eg. Gilbert, Osborne & Fensham, 1982; Griffiths & Preston, 1992; Renstrom, Andersson & Marton, 1990) are presented in Table 1. These misconceptions seem to relate to inadequate student models of matter, its constituent particles, the spacing and arrangement of particles, and changes in these spacings and arrangements which occur during changes of phase.

Table 1
Students' misconceptions: The particulate nature of matter

The nature and characteristics of particles
1. Size of molecules:
   A water molecule is "macro" in size.
   Atoms are large enough to be seen under a microscope.
2. Water is a continuous homogeneous mixture of the elements hydrogen and oxygen.
3. Atoms and molecules have macroscopic properties, eg. expand when a substance is heated; freeze when a substance is frozen; malleable etc.

The space between particles and the way particles are arranged
4. Matter is a continuous and there is no vacuum or space between particles.
5. There is considerable space between molecules in a liquid.
6. Gases are arranged in an orderly rather than a disorderly fashion.

Molecules in different phases
7. Atoms and molecules may have different sizes, shapes and weights depending on the phase:
   Water in the solid phase has the largest and heaviest molecules.
   Water in the solid phase has the smallest molecules.
   Atoms and molecules become larger on melting.
   Atoms become larger as they change from liquids to gases.

Changes of phase and the effects of temperature
8. Melting and boiling of molecular compounds are processes in which covalent bonds within molecules are broken.
9. Bubbles in boiling water are made up of heat, air or hydrogen and oxygen (from its decomposition).
10. Gases have no mass.

Adapted from Garnett et al. (1994).

Common student misconceptions which suggest that boiling is the release of air bubbles from the liquid, or that boiling water involves its decomposition into hydrogen and oxygen, are now widely recognised. Other commonly reported misconceptions include the idea that individual atoms/molecules exhibit the macroscopic properties of the substance such as expanding when heated, freezing, and malleability; and variations in molecular size/mass associated with phase transitions.

In a study of Year 7-9 Swedish students, Renstrom et al. (1990) identified six different conceptions of matter which they described as "logically related categories of description". The six categories represent a progressive development of students' understanding from a 'homogeneous substance' model to a conception based on 'systems of particles'. In the most basic 'homogeneous substance' model, matter is visualised as being continuous and completely homogeneous, rendering an understanding of phase changes or different substance attributes impossible. More sophisticated models employed the notion of 'substance units', initially viewed as grains or small particles, but increasing in sophistication as atoms and atomic groupings and their interrelationships are incorporated. It is evident from this and other studies that the development of a particulate model of matter, including an understanding of the nature and spacing of the constituent particles, is a considerable hurdle for many students.

Typically textbooks and teachers use illustrations in an attempt to represent this particulate model. However, as Hill (1988) has pointed out, textbook diagrams are often misleading in that the expansion of solids on heating is often exaggerated, particulate spacing in liquids is suggestive of considerable compressibility, and the change in density from the liquid to the gas state is often under-represented. As well, textbook diagrams sometimes represent molecules as single spheres and, on other occasions, place more emphasis on the atomic groupings within molecules, depending on the concept or phenomenon being considered. This is also likely to be a source of confusion to some students.

Chemical equations

Several studies have investigated students' understanding of chemical equations and the processes they represent (eg. Ben-Zvi, Eylon & Silberstein, 1987; Garnett, Hackling, Vogiatzakis & Wallace, 1992; Yarroch, 1985). Some of the misconceptions evident from these studies are listed in Table 2.

Table 2
Students' misconceptions: Balancing and interpreting chemical equations

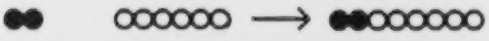
1. Subscripts in formulae are numbers used in balancing equations (and do not represent atomic groupings).
2. Equation coefficients are numbers used to mechanically balance equations (and do not represent the relative numbers of species reacting or being produced in chemical reactions).
3. Chemical equations do not represent chemical reactions at a particulate level.
4. Chemical equations do not represent dynamic processes in which particles/molecules react with one another to produce new particles/molecules by rearrangement of the atoms.

Adapted from Garnett et al. (1994).

In interviews with Year 12 American students Yarroch (1985) found that about half of the students who were able to balance chemical equations were unable to draw a reasonable diagrammatic representation of the equation at a particulate or molecular level. Students often drew representations consistent with the total number of atomic particles involved but inconsistent with the formulae of the substances involved and the coefficients in the equation. Yarroch concluded that many students simply regarded formula subscripts and coefficients as numbers distinguished by their location in an equation rather than in terms of their chemical significance. For example, when students were asked to draw diagrammatic representations of the equation

$N_2 + 3H_2 \longrightarrow 2NH_3$ they would commonly represent $3H_2$ as H_6 and $2NH_3$ as N_2H_6 as shown below.

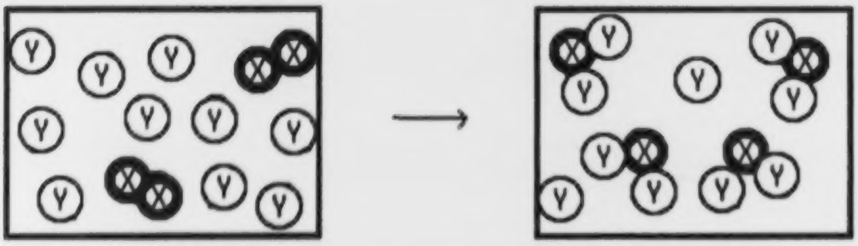
$N_2 + 3H_2 \rightarrow 2NH_3$



Ben-Zvi, et al. (1987) reported that substantial numbers of Israeli students had inappropriate ideas about both structural and interactive aspects of chemical reactions. Students often represented the molecular compound Cl_2O as two fragments, Cl_2 and O; and failed to distinguish between N_2O_2 and $N_2 + O_2$ when considering possible products of a reaction between N_2 and O_2. Examples of student difficulties with the interactive nature of chemical reactions are illustrated by the reaction between N_2 and O_2; some students thought N_2O_5 could not be formed because of the need for three additional O atoms; others thought NO could not be formed because the mass of the products would be less than that of the reactants.

Garnett et al. (1992) investigated some Year 10 Australian students' abilities to balance chemical equations and apply an understanding of equations to 'simple' stoichiometry problems. As reported by Yarroch (1985) students were often unable to draw diagrammatic representations of equations and many students showed a lack of understanding of the different use of subscripts in formulae and coefficients in chemical equations.

In this study students also had considerable difficulty when asked to formulate the equation which described the reaction represented by the following diagram:



Some students merely added up the number of species of each type in the 'before' and 'after' boxes with no recognition that one of the species was present in excess or of the need to simplify the coefficients in the equation. As well, many students disregarded the different meanings of formulae subscripts and equation coefficients.

It seems apparent that many students lack a conceptual understanding of the submicroscopic particulate nature of matter and the changes represented by chemical equations. In addition, Andersson (1986) and Ben-Zvi et al. (1987) identified students who held a 'static' rather than 'dynamic' understanding of chemical reactions. Such students lacked the understanding that a chemical reaction is a dynamic process in which particles/molecules react with one another to produce new particles/molecules by a rearrangement of the atoms through breaking bonds and forming new bonds.

Clearly, many students' ability to balance and understand chemical equations is severely limited by their lack of understanding of the submicroscopic particulate nature of matter and their inability to visualise the dynamic process of a reaction on a particulate level. This inability to visualise reactions probably also limits their success in solving stoichiometric calculations, particularly where these are of a non-routine nature.

The difficulties students experience because of the abstract, unobservable, particulate basis of chemistry was previously reported within the Piagetian epistemological framework (Herron, 1978) and several authors (Gabel & Sherwood, 1980; Garnett, Tobin & Swingler, 1985; Herron, 1978) advocated the use of appropriate concrete models to help students develop a concrete model of the nature of matter. Modern multimedia technology has the potential to provide students with simulations of the submicroscopic/particulate nature of matter in its various states and the processes underlying physical and chemical change.

Chemistry at the macroscopic, submicrpscopic and symbolic levels

Johnstone (1991) has proposed that chemistry is taught at three levels. The macroscopic level is sensory and deals with tangible and visible phenomena (eg. salt dissolving in water). The submicroscopic level provides explanations at a particulate level (eg. disruption of the ionic lattice and ions, surrounded by water molecules, moving into solution). The symbolic level represents processes in terms of formulae and equations (eg. $NaCl(s) + H_2O(l) \longrightarrow Na^{+}(aq) + Cl^{-}(aq)$). Johnstone believes that insufficient attention is given to understanding chemistry at the submicroscopic level.

In addition Johnstone (1991) has pointed out the difficulty for students when teachers move quickly between these different levels. Perhaps it would be useful to students to point out these different ways of knowing and to clearly identify for students which level of thinking is being used at any particular time. From the research evidence available at this stage, it appears that students have most difficulty in dealing with the submicroscopic which is, of course, outside their experience and can only be made accessible to students through the use of models, analogies or computer graphics.

Major difficulties for students of chemistry are the abstract, unobservable particulate basis of chemistry and the manner in which practising chemists and chemical educators move between the macroscopic, submicroscopic and symbolic representations of chemical substances and processes. These difficulties represent significant problems for chemistry educators but modern audiovisual technologies including the use of computer graphics provide exciting opportunities to present students with acceptable concrete representations of the particulate basis of chemical structure and behaviour.

Several studies (Hameed, Hackling & Garnett, 1993; Zietsman & Hewson, 1986) have indicated that it is possible to develop computer based instructional materials based on a conceptual change pedagogy which facilitate improved student understanding. This instruction is most likely to be successful when it provides visual concrete representations of unobservable processes and events, and causes students to reflect on their present conceptions. Interactive multimedia materials are eminently suited to the simulation of chemical processes using dynamic graphical representations of molecular interactions.

Animations in Computer-Based Learning

Animations have become an increasingly popular component of computer-based instruction. Despite the many instructional advantages to be gained from animations in learning sequences, many applications tend to under-utilise this resource (Rieber, 1991). A number of recent studies have demonstrated particular advantages to be gained in science education through the use of animations in teaching concepts and processes (eg. Mayer & Gallini, 1990; di Sessa, 1982; White, 1984). The development of interactive multimedia technology provides an accessible and convenient platform with which further exploration and inquiry in this field can be conducted. Words and pictures have become the principal media for multimedia instruction.

There are several theories that guide the use of animations and graphics as instructional tools. Mayer and Anderson (1992) suggest the value from these media in instructional settings is maximised when they are used in a contiguous rather than separate fashion. Support for this notion is derived from the dual-coding theory (Paivio, 1979) which is founded on the assumption that human cognition develops from two distinct information processing systems, one that represents information verbally and the other that represents information visually. The theory assumes that two codes are better than one and that each has an additive effect. Memory and understanding are greatly enhanced when information is coded in both forms. With respect to animations and illustrations, the pictorial elements are able to provide the means for information to be coded in both forms.

Theoretical support for the animations and pictorial elements in this research project is evident in much of the inquiry that has been conducted into the use of graphics and animations in computer-based learning. Mayer (1989) describes several necessary conditions for meaningful learning to be achieved with animations including the capacity of the learner to construct a meaningful mental model and likewise the capacity of the animation to effectively direct the user's attention to help build the connections necessary for meaningful learning.

Rieber (1990) discusses the problems that can confront novice learners interacting with animations. He argues the need to provide relevant cues and signals to direct the learners to the relevant elements of the animation. Finally, research has demonstrated that the greatest contributions of animations in computer environments are to be derived from interactive applications where the learner exerts some degree of control and influence over the dynamic situation. The instructional value is derived from the practice and the knowledge construction that can result from experimentation and guided activity.

Other promising outcomes from the use of animations in science education applications stem from the incidental learning that can be achieved concurrently with the planned goals. Rieber (1991) describes a study in which students' interactions with animations in a computer-based learning environment resulted in significant achievement gains in incidental areas. Students were found to have developed concepts and understanding beyond those planned for the instruction through their interaction with the graphical elements. The use of animations in chemistry simulations, while aiding students understanding of chemical equations, also has the prospect of contributing to understanding of other concepts such as kinetic theory and bonding.

Description of the project

This project aims to develop across-platform interactive multimedia materials to help beginning students to understand the particulate basis of chemical reactions, their symbolic representation as chemical equations and to apply this understanding when balancing equations and solving problems based on equations. The materials will simulate the particulate/molecular basis of chemical reactions using dynamic graphics which provide concrete representations of processes which are abstract and unobservable and therefore difficult for students to comprehend. Students will interact with the materials so that their conceptions of the molecular basis of equations are challenged and clarified.

The materials will be designed so that:

1. they are interactive and provide for individualised instruction (but could also be used in lecture and tutorial situations);
2. they use dynamic graphics to simulate chemical reactions at a particulate/molecular level so that students attain a concrete representation of the processes described by an equation;
3. they incorporate a conceptual change pedagogy that will challenge students' misconceptions regarding chemical equations in a way that promotes the development of accurate scientific conceptions;
4. they can be used in Macintosh and DOS-based computing environments.

The materials developed in this project will address the following topics:

1. the molecular nature of chemical reactions and the symbolic representation of reactions as equations;
2. balancing chemical equations;
3. interpretation of chemical equations in molecular terms;
4. relationships between coefficients in chemical equations (basic stoichiometry);
5. limiting reagent;
6. calculations involving masses, gas volumes and solutions.

The materials developed will be published on CD-ROM and will be useable on multimedia PCs with a range of colours and sound. Macromind Director will provide the shell into which the following will be imported:

- animations as Quicktime images;
- sound - produced using Sound Edit software;
- scanned images - enhanced using Photoshop.

Sample Screens

Figure 1

The gases are released by the user into a mixing chamber.

Figure 2

An option allows the user to view a magnified image that shows the motion of the gas particles in the separate chambers.

Figure 3

A further option allows the user to mix the gases and observe a representation of the chemical reaction taking place.

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Figure 4

An agent is used as an integral part of the instructional design enabling voice to complement the text images.

Figure 5

The Chemical Equation Calculator provides the means to practise balancing the equation representing the chemical reaction just viewed.

Conclusion

This instructional package is designed to improve students' understanding of the particulate/molecular basis of chemical reactions, and their ability to interpret chemical equations and solve problems based on equations. The provision of concrete representations of unobservable entities and processes, and the use of an interactive and, where appropriate, conceptual change pedagogy, should facilitate students' achievement of scientifically acceptable conceptions of chemical equations and their application.

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PROFILES OF ACHIEVEMENT IN SCIENCE IN WESTERN AUSTRALIAN GOVERNMENT SCHOOLS: THE MONITORING STANDARDS IN EDUCATION 1994 REPORT

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Background

The MSE project was established in 1989 to report on student performance in key learning areas in government schools in Western Australia. It provides information for system level planning. Following the assessment, a schools' version of the materials is produced and distributed free to assist schools to measure their students' performance against Statewide standards. In 1990 and 1992 student performance in English and mathematics was assessed. In 1993 the project conducted the first comprehensive Statewide assessment of student achievement in science to be carried out in WA. Findings are published in its report *Profiles of Student Achievement: Science in Western Australian Government Schools 1993* (Education Department of Western Australia, 1994a). A random sample of 8500 students from schools in WA at Years 3, 7 and 10 was selected. Seventeen different forms of assessment tasks were developed with students attempting one or two forms with links between the year levels and between the content forms.

The National Statements in Science (Curriculum Corporation, 1993a; 1993b) and the Western Australian Working Edition of the Science Outcome Statements (Education Department of Western Australia, 1994b) have been used as a basis for a standards framework describing what students are expected to achieve. Five strands of science are described: Working Scientifically, Life and Living, Earth and Beyond, Energy and Change, and Natural and Processed Materials. The National Statements document indicates that by the end of compulsory schooling, a significant proportion of Year 10 students could be expected to reach Level 6 (Band 4). Generally, it indicated that Level 2 is matched to Year 3 and Level 4 to Year 7. Figure 1 shows this 'expected' performance based on these National performance levels. Some suggestion that this needed review was given by the MSE report of 1992 in English and mathematics (Education Department of Western Australia, 1993) which showed that student performance for these areas at Year 10 was at Level 4.

Task Characteristics for the 1993 Program

The form of testing used in the 1993 MSE program was more demanding than many of the traditional approaches to science assessment. The tasks did not rely on multiple choice or short answer questions, as many traditional approaches have done, but required students to demonstrate their understanding of scientific concepts and processes by applying them to situations dealing with problems and issues found outside the classroom. The majority of tasks were open-ended and students expressed, in writing or diagrammatically, their understanding of concepts. Investigative tasks assessed students' skills in planning and conducting investigations. The items asked students to apply their understanding to novel and everyday situations in extended responses. Items were developed in cooperation with ACER, with some taken from forms developed for a Victorian study (Adams, et al., 1991) and others developed especially for WA.

A large number of student responses for each item were collected from extensive trialing. These responses were categorised and a marking key created which was based on a model of partial credit. Rather than marking a response right or wrong, scores were awarded from 0 to up to 4 for each item to indicate the relative difficulty of five response categories. A higher score indicated a response that students found relatively more difficult and occurred less frequently. Item Response Theory (Rasch analysis) was used to generate maps of the relative difficulty of each response. A scale of 0 to 800 was used to indicate the threshold or item ability estimate. In the example, Year 7 and 10 students are mapped against the scale.

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Each 'X' represents 7 students, with the relative difficulty of each item indicated by its number. For example, 47.1 (item 47 with a score of 1) was less difficult than 45.2 (item 45 with a score of 2).

Each item was matched to the Level description and Outcomes from the Science National Statements. Figure 1 shows these as 'actual' performance levels. For example, item 47.1 matched Level 2, and 45.2 fitted best the description for Level 4 (shown as small circles in Figure 1). This process was done independently by the two researchers, and by a group of Year 3, 7 and 10 classroom teachers. On occasions it proved difficult to determine the level because of the imprecision of the outcome statements due to their very broad and general structure and the relatively low number of specific pointers. The levels most clearly defined by the Outcome statements were Level 4 and Level 2 as for the majority of these items there was independent agreement of the level by the researchers.

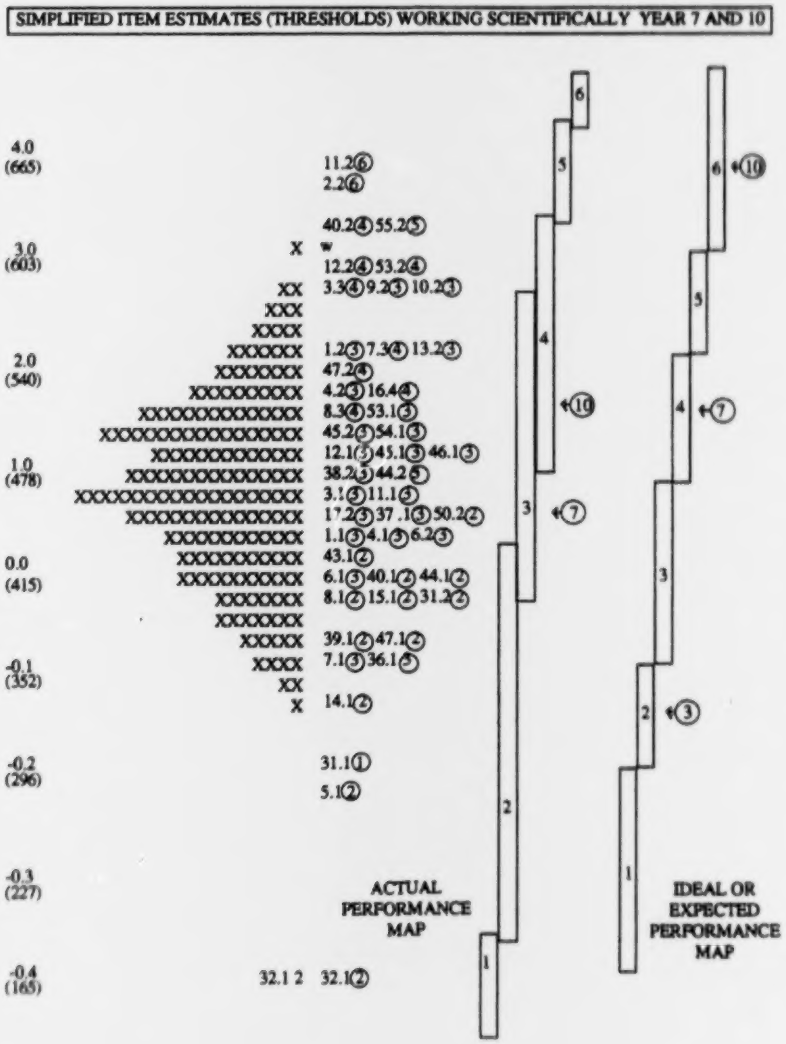

Figure 1. Response map for Working Scientifically strand with ideal and actual level boxes.

The range of responses to the assessment questions was organised onto item maps, and responses of the same level were clustered. For each strand, the ranges for six levels were produced and represented as 'level boxes'. Cut off points for each level box were determined by recognising clustering, and by establishing a point midway between the two outlying responses of that level at the bottom and top of the range. There was considerable overlap between levels.

Extreme misfitting of items did occur in some cases. For example, two responses that had been categorised as Level 2 were clustered with other responses of Level 5. In these cases, a re-examination of the outcomes statement and the task was conducted, and in each case when this occurred it was possible to find a reason for the apparent discrepancy. At times it was because the description of the response was not accurate, and on other occasions the skill or knowledge being tested was strongly influenced by the literacy demands of the item.

Response Maps

The response maps clearly showed that older students were more likely to give responses of greater complexity than younger students. The mean scores of students in Years 3, 7 and 10 showed statistically significant increases, indicating that students demonstrated higher levels of understanding in all strands as the number of years at school increased.

Due to the process of individually allocating a level to each response, then identifying clusters of responses with the same level, the range of levels, shown as rectangular 'level boxes,' varied substantially for each substrand. Converted into the 0 to 800 scale, for example, the Working Scientifically strand for Level 3 extended from 378 to 584 , yet Level 3 for the Natural and Processed Materials strand extended from 438 to 586. For Energy and Change, the cut off points were 462 and 507. This variation existed for all strands.

Another noticeable feature of the strand maps is the extensive overlap or transition between each level. For some levels, particularly Levels 2 and 3, there was approximately 50% overlap. This led to achievement for students being reported as two levels, such as '1/2' which indicated that students demonstrated the more complex skills and understandings of one level, with some of the less complex ones of the next higher level. This may be due to items, particularly in the content strands, being better placed in another level, as well as the influence of the curriculum. This extensive overlap of levels supports a finding by the OSMIS project in WA that "the levels are clearly not of equal 'developmental' difficulty" (Rowe, 1994, p. 12). This suggests that the outcomes statements in their present form unsuccessfully group outcomes at one level that more realistically could belong to a number of different levels. The distinctive nature of each level needs to be clarified so the outcome statements can more tightly describe achievement as a series of discrete stages.

Results

Students performed at a higher level in Working Scientifically than any other strand, as shown in Table 1. A variety of factors may have contributed to this result: that students worked in groups; that the activities were practical and appealed to students interests; and that teachers were required to give a review of scientific investigation procedures before students began the investigation. For some content strands, there appeared to be little growth between the years tested. However, although the overall level for the two years may have been similar, in all cases when the performance was examined in more detail, older students were demonstrated more complex skills and understandings. For example, in Earth and Beyond, skills shown by both Year 7 and Year 10 students are best described as Level 2/3. However, the responses given by Year 10 students were typically more complex and occurred more frequently than they did for Year 7 students.

Table 1

Levels of Performance of WA Students in Science 1993

Year Level	Working Scientifically	Earth & Beyond	Life & Living	Energy and Change	Natural & Processed Materials	All Four Content Strands
3	2/3	-	1/2	1/2	1	1/2
7	3	2/3	1/2	2	1/2	2
10	3/4	2/3	2/3	2	2/3	2/3

To generate information on students' level of performance in general science concepts, a composite map of all students on all four content strands was generated. For Year 3, this generalised science ability was placed at Level 1/2, for Year 7 students at Level 2 and Year 10 students demonstrated skills at the more complex aspects of Level 2 with the less complex of Level 3. Since items for Working Scientifically were not linked to those of other strands these results were not included in the composite science ability.

Generally male students performed at a higher level in strands that related to physics and chemical concepts. Female students typically showed higher performance in Life and Living which deals mainly with biological concepts. There was no statistically different performance for males and females in Working Scientifically. For all strands the performance of students with an Aboriginal or Torres Strait Islander background, and for those with a non-English speaking background was lower at each of the three years assessed.

Supplementing the Level Statements

All response descriptions were collected and linked to the Science National Profiles for each of the five strands, at each of the six levels. These descriptions of skills, knowledge and understandings have the distinction of being based on performance demonstrated by a very wide cross section of WA students at key stages of their schooling – the end of junior primary, primary and lower secondary. They have been linked to existing strands and substrands of the National Statements, with additional aspects being highlighted when a clear track of conceptual development was evident. These descriptions will be of value in describing what it is that students can do at each level of achievement in specific terms, and also indicating how these skills and understandings link to create a sense of conceptual development which is at times difficult to track in the existing outcome statements in science.

Extended level descriptions are given for two strands in this paper – Working Scientifically as the strand that relates to concepts of scientific method and ways of knowing, and Energy and Change as an example of subject (physics) related conceptual development.

Descriptions for Working Scientifically

Level 1

Students are beginning to notice and describe in a scientific manner their immediate world, simple events and can reflect on what they know.

Conducting Investigations: Students can determine the largest and smallest object of a group, for example of seeds, when working independently. They can measure a short line accurately using arbitrary units such as seeds.

Observation: They propose reasonable explanations for natural phenomena but may not always focus on observable evidence.

Level 2

Students are sharper in their discrimination when describing events, and solving problems. They observe with a view to patterns, explanation and causes. With support when doing investigations, they can analyse their procedures and suggest improvements.

Aim: They can state a purpose of a given investigation, but it may be not related to the problem under investigation.

Planning Investigations: They can plan an investigation which involves a number of steps, for example: determining which brand of tennis ball will bounce the best. They may not include the notion of 'fairness' when planning, but can list equipment, get some results and make a simple conclusion.

Conducting Investigations: Students can independently follow written instructions to perform given investigations following a number of simple steps. They sort objects into groups but are likely to make mis-sorts, and are usually unable to define the rule used. They are able to carry out a plan they have made in response to a given problem, and can use simple equipment such as balls, rulers and timers.

Presenting Results: Students can interpret a bar graph with some accuracy, and can make reasonable estimates based on experimental data. They can put results in a clear, but not systematic manner.

Making Conclusions: Students can make a conclusion, usually based on their own personal response and prediction, rather than on experimental data.

Level 3

Students are more reflective about their investigations and compare different ways of solving a problem or testing an idea. They take 'fairness' into account, and can argue from data and from personal experience. They are beginning to use scientific vocabulary when conducting investigations.

Aim: Students are able to state or imply an aim for their investigation that relates to the problem being investigated.

Planning Investigations: With familiar equipment or simpler experiments they can list all steps clearly and sequentially and specify how the equipment will be used. They can give a definition of terms such as 'best' but it is not measurable. Can recognise an investigation's purpose, for example to determine what conditions snails prefer.

Conducting Investigations: Students have some ability to control a few relevant variables in their own investigation. Can recognise when an investigation is fair, but are not always able to make a design improvement suggestion. Can suggest the purpose of a 'control' when it is shown in a drawing of an experiment but do not state it is a way to check basic assumptions.

Presenting Results: Can set out results systematically. They attempt to adjust the level of accuracy in measuring to suit the level required. Attempt to draw a graph based on experimental data with inaccuracies that make the graph difficult to interpret. Can read a graph of time and temperature with some accuracy and extend it to a new value based on perceived trends.

Making Conclusions: May make a conclusion not actually supported by the data, or limit their conclusion only to the experimental data.

Level 4

Students use equipment more effectively to generate data from investigations, assess the reasonableness of their findings, and reflect on the need for accuracy and reliability when drawing conclusions. They have a strong awareness of the need for the control of variables.

Aim: They are able to recognise the purpose of an investigation but are not able to state it as a formal scientific 'aim'.

Planning Investigations: Students are able to give a measurable quantifiable definition of terms for experiments. Are able to follow a series of steps to process objects to classify them correctly, for example: to categorise seeds for a specific property such as oiliness. Can determine if an experiment is fair and are able to suggest improvements in design.

Conducting Investigations: Students can suggest ways to control two or three relevant variables to make an investigation 'fair'.

Presenting Results: Students can measure length in an investigation with a high level of accuracy which is appropriate to the level required by the purpose of the investigation. Draw an accurate graph from their own investigation, with occasional minor errors particularly with complex data, such as using fractions of tablets and time taken to dissolve under different conditions.

Making Conclusions: Beginning to make conclusions based on the investigation's data, but are not always able to go beyond the data and relate it to other information from other sources.

Level 5

Students are characterised by increasing initiative in planning and conducting investigations. They can, with increasing confidence, propose options, explore in their minds the consequences of each, and select equipment and techniques for their investigation. They focus tightly on the use of quantitative data, deliberately organising data to assist their analysis and reveal patterns.

Aim: Students can recognise and state the aim of a given experiment, and can state and plan their own precise aim for their own experiments.

Planning Investigations: Students can describe a clear and explicit sequence for a given investigation, stating all steps and containing all essential information.

Conducting Investigations: Students can state the purpose of a 'control'.

Making Conclusions: Draw conclusions about the problem under investigation, based on the data from it. They may include relevant information from other sources, and refer to the original purpose of the investigation. Can reflect explicitly on their conclusion in the light of the original aim and may be able to make an inductive assertion or generalisation about their result.

Level 6

Students have a clear picture of the value of scientific knowledge as reliable knowledge, based in reproducible observations, experiment and logic. They can employ a scientific way of working as part of their everyday thinking, referring to processes of investigation, and an awareness of how contextual factors shape science development.

Aim: Students are able to state an hypothesis that relates to the given problem.

Descriptions for Natural and Processed Materials

Level 1

Nature of Matter: They can classify matter based on examples of each, so that water is not generalisable concept of liquid, but is linked with how it occurs to them, for example 'water' is 'what comes out of a tap' or 'what you can do with it' or 'you can pour it.' They may distinguish materials only by their source or purpose, for example milk and water are for drinking and honey is for toast. They can group like materials, for example milk, honey and water, on the basis of a common property such as 'they all are runny'.

Changes in Materials: Students are able to observe changes in materials and give very simple explanations based on what can be directly sensed, for example cooking is seen as drying out. They adopt plausible misconceptions based on direct sensing, for example the water that has condensed on the outside of a container has come from inside it.

Recycling: Gives a simple description of recycling as using a specific item again, for example 'use a milk carton again'.

Level 2

Nature of Matter: Students can give simple explanations of common events, which may be plausible misconceptions, based only on direct observation. Thus, dissolving is seen as visible grains becoming invisible because they are so small. Are developing skills in simple classification of matter- based on comparison of one aspect such as hardness or sweetness.

Changes in Materials: They observe and describe some reversible changes in water such as condensation and evaporation as the visible level based on the understanding that water can look different, but it is still water. They are not able to explain how this happens. They describe cooking as mixing, and understand that is not a reversible change. They can not explain how it happens, but understand the need for heat to make it not reversible.

Recycling: They are able to give reasons for recycling as a general concept of reuse, or change, or of benefit to the environment, but cannot define it in general terms.

Level 3

Nature of Matter: Students can differentiate between solid, liquid and gaseous states using a holistic or continuous model -they describe a solid only by example such as 'a block of wood is a solid'. They explain natural processes such as condensation as a change of form (not of

'state') that is dependent on a temperature change, for example from vapour water to liquid water. They can use the specific terminology of solid, liquid and gas to group general properties a number of substances may share.
Changes in Materials: They are beginning to grasp a simple understanding of reactions at the continuous model level, for example in cooking they understand that bubbles are air (and not heat) , but are not yet able to explain how they are formed.
Recycling: They define recycling as using original material again in different forms.

Level 4
Nature of Matter: Students have developed the concept of matter as made up of small particles such as molecules and atoms. They can use this model to explain how a 'state' such as gas or liquid is determined by the arrangement of these particles.
Changes in Materials: They can explain the conditions which influence change in materials, such as applied heat causing air to expand, and how this is actually steam, and how this leads to the development of bubbles and the evaporation of water. They are able to describe some reactants in a chemical reaction such as burning.

Level 5
Chemical reactions and the Nature of Matter: Students can use simple models of atoms and molecules to explain chemical reactions such as cooking as changes in the molecular structure. They are beginning to understand the relationship of energy before a chemical change and the energy after the reaction.
Changes in Materials: They can use a molecular model to explain events such as dissolving. They relate terms such as heat to the molecular level, and use them to describe common events such as the changes of 'state' involved in evaporating and liquefying.

Level 6
Chemical reactions and the Nature of Matter: Students identify the reactions involved in chemical changes such as the products of burning and recognise the direct relationship of these products to the weight of the original reactants. They understand the balance of energy in a chemical reaction.

Conclusion

In conclusion, the MSE Report on science (Education Department of Western Australia, 1994a, p. 3) identified three consistent 'barriers to achieving the desired goals' in science education as "the relatively low priority and small amount of time devoted to science education in primary schools ... , and the consequent generally low level of understanding displayed by primary students; the effect of an increasingly crowded curriculum on the ability of secondary schools to cover science syllabuses effectively in the time available; and the need to integrate science education in schools with the application of science beyond school." It is critical that revisions of student outcomes and the concept of levels of achievement intended to improve student abilities in science be based firmly on examples of actual, rather than idealised, student performance. Assessment tasks to determine student levels of achievement should be designed to involve student understanding and application of knowledge and skills to a variety of contexts, as this taps into their long term understanding and competency to use their knowledge, rather than more superficial abilities of rote learning or memorisation of facts.

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A CONSTRUCTIVIST APPROACH TO SCIENTIFIC LITERACY FOR TECHNOLOGY STUDIES STUDENTS

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Background to the Study

The Bachelor of Applied Science (Technology Studies) degree programme at Edith Cowan University has a double major configuration. Students take twelve units of technology studies in parallel with ten units of their supporting major and enter the degree programme with a wide range of prior science knowledge and experience. By the time they reach their third year, because of the choice available, this range has increased further.

It is against this background that the third year unit, Communications Technology, is taught. This unit has several roles within the course. In addition to covering the content area associated with communications technology, it is the second of two units used to teach physics literacy through the vehicle of technology. As a third year unit it is also designed to draw on material in previous units and to meet the needs of individual students in the area of communications technology.

The Problem

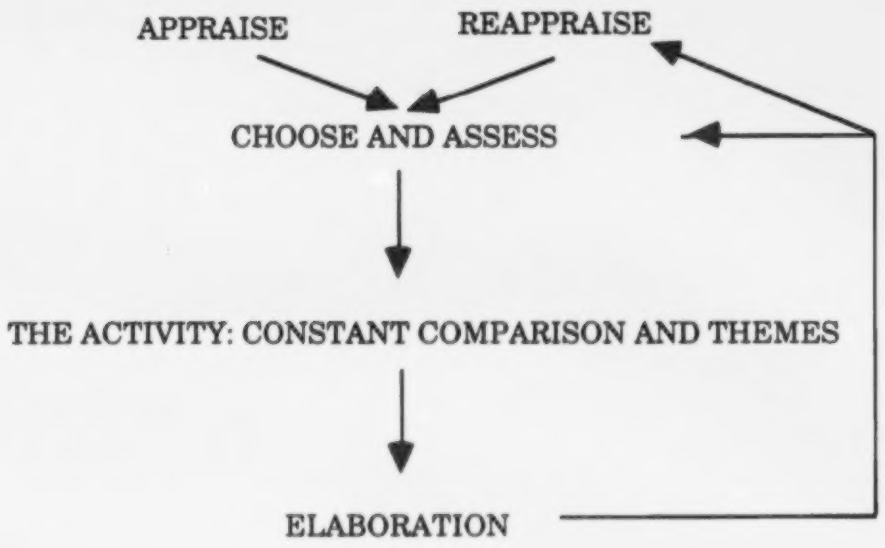
Any unit on communications technology within a degree programme faces the difficulty of dealing appropriately with the current explosion in communications technology. The wide choice given to students in their supporting major creates problems which manifest themselves in the range of student prior knowledge of physics (from year nine science to third year university physics); the diversity of students' interests and the wide range of potential areas for application of the knowledge associated with communications technology.

When faced with such diversity of background, interest and application, the lecturer is tempted to aim for the middle ground and accommodate the extremes in the best way possible. Practically this could mean compressing the material into a first year physics format. This was not acceptable as it

- devalued the students' present analytical skills;
- failed to extend students and give them 'third year' confidence;
- would bore those with advanced physics skills;
- would effectively exclude those with little physics background from meaningful science learning forcing them to adopt techniques based purely on strategies for passing examinations;
- would increase the insecurity of those with little physics knowledge; and
- runs counter to the philosophy of the degree which regards all levels of knowledge equally acceptable.

The Solution Trialed in 1994

The solution trialed in 1994 used a model developed by Fetherstonhaugh (1993). Based on personal construct psychology (Kelly, 1955) and described by Fetherston (1994), this model uses theoretical summary propositions that are made explicit through five key operations as shown in Figure 1.



During the 'Appraise' phase both the teacher's and students' constructs are made explicit and then used as a basis for choice in order of subsequent content. Students then 'Choose and Assess', which places the responsibility for learning on the student. Throughout 'The activity' phase there is an emphasis on constant comparisons; their ideas versus each others; their ideas versus texts. The learning process then moves to the 'Elaborate' phase where students apply and consolidate their new knowledge. Finally they 'occasionally Reappraise' and monitor the changes in their thinking.

Existing materials were easily adapted to this new approach. The lecture and lab/tutorial components were separated and the lectures were used only to introduce students to the current use of new communications technologies. The structure of the lab/tutorials was designed to be sufficiently flexible to permit each student to start from their current knowledge and build on this.

The material in the lab/tutorial section was divided into modules of two different types. Type One modules contained a well defined subset of essential material. Type Two modules were more open-ended and allowed students to investigate a wide range of problems in different areas. With the exception of three pairs of linked modules, students could take the modules in any order (consistent with the model) provided that at the end they had covered or had prior knowledge of all the Type One modules and had worked on at least two of the Type Two modules. Within modules there were many alternative pathways (again consistent with the model). Students had a large degree of choice over the amount of practical work which they carried out.

Students worked through this module in small groups using discussion within their groups in each of the phases (Appraise, Choose and Assess, The activity, Elaborate and Reappraise) as an essential part of the learning process. They were asked to use journals to record their learning progress. It was expected that the journal would act as a powerful learning tool by forcing students to verbalise the learning process and thereby assisting with appraisal of their learning. The 'Elaborate' phase encouraged students to address links to previous units and to address interests arising from the diversity of their supporting majors. It soon became obvious that the more thoughtful groups also saw the connections to the lecture programme. The lecturer was available as a resource for use by groups throughout the process.

An outline structure of a typical module is given below. Each module began with a title and an estimated time required for completion.

The *APPRAISE* section began with a reminder regarding a journal entry. Before they started students recorded the date, their own background and prior knowledge, and their initial goals for this module.

CHOOSE AND ASSESS contained another reminder regarding journal entry. Relevant information such as some introductory text, introduction to the modules and key concepts were presented. Students were then asked to identify their own understandings of key concepts and to choose their learning path.

THE ACTIVITY began with students identifying their own understanding of concepts involved with the activity. While doing the activities they were asked to record how their understandings compared with (for example) the notes supplied on the next page or with other students in the group. Sometimes they were asked to supply diagrams to explain statements presented. Discussion and comparison of ideas were the key learning activities in this section.

The *ELABORATE* section also asked students to make journal entries. Activities were presented to allow students to extend and test their new knowledge in real life situations to assist in the process of constructing meaningful knowledge. They were also requested to make lab-notes where appropriate using their own judgement as to when this was necessary. Additional questions were presented to link in with relevant previous units and students' interests arising from the diversity of supporting majors. Issues for group discussion, resources which they found particularly useful and in what way they used them, and a record their progress were also made at this point.

The *REAPPRAISE* section asked students to identify and note down any changes which have taken place in their understanding of the topic. They were also asked to assess the value of the module and to review their choice for your next module

Implementation

As this was a pilot implementation, evaluation was restricted to qualitative data from students. The students' initial reaction on being told about the way the lab/tutorial section of the unit would run was one of stunned silence. The lecturer took an early break to give the students an opportunity to talk among themselves and articulate some of their fears. When asked later to describe how they felt at the start of the unit, students mentioned feelings of uncertainty, confusion and difficulty. Typical responses were:

- *Difficult to understand what was required*
- *I found it a little daunting to begin with but eventually got the hang of it*
- *Confusing but gradually got used to it*
- *Almost lost at the start of semester*

This is not surprising given how different this approach was to the rest of the units which they had studied. Similar initial reactions were observed by Fetherston when working with a group of year nine students (Fetherston 1993)

When asked to describe the changes which happened during the semester, the picture changed considerably with most students recording positive outcomes. Typical comments included:

- *Have learned to view most things from different angles and perspectives and to learn in a more mature way*
- *Gained a greater independence. Taught myself some of the concepts that are related to physics*

One group however continued to resist the change until the last few weeks of semester. One member documented this graphically:

> "Perhaps the greatest lesson my group learnt was how reliant we had all become on direction by a lecturer or a lab assistant. We were given the option in this unit of pursuing whichever direction took our fancy as we had all had similar physics background. To be given freedom of this type was so unusual in our collective 50 years of scholastic experience (certainly since kindergarten) that we spent far more time looking for the trap and the usual hoops that you have to jump through, than in contemplating where we really wanted to go. In the end we conservatively plodded

> our way through the physics we already knew again, rather than grasp the golden ring of opportunity. ....
>
> My prime message to those like me in future is: Wake up!! Do not be a zombie-like marks calculator when choosing the modules you are going to pursue. Just select what interests you from the type two modules and go into whatever aspects you wish. Why be a passenger when you can drive the car yourself!!"

This group had the best knowledge of physics but also a strong initial conviction that physics was about facts and not a subject for discussion, they were also cynical over the use of the journal. It appears that their epistemology regarding learning and the nature of science could well have inhibited change. This was in stark contrast to most of the students who made comments about the use of the journal like:

> "I recommend the use of a journal as suggested in the unit outline. The concept of a journal vocalising the learning process can be successful if utilised correctly. However I must confess to finding it difficult at times to write down what I was thinking or feeling. It did not seem to be important if it did not involve facts. After practise the technique becomes a little easier and worthwhile even though it is time consuming "

Despite the difficulty experienced by this one group, on balance the trial appears to have produced more real learning, interest and application than the alternative of giving a formal lecture course to a sea of faces, half of which were bored and the other half confused. More data are required to substantiate this initial impression.

Exciting opportunities were available for students with a good knowledge of physics to extend their knowledge. In some groups the amount of work done was considerable and commented on negatively by two students, who had found the pressure of their responsibility to other members of the group onerous. The approach proved to be particularly empowering to the groups of students with the least physics background and this is an impressive and encouraging result. One of these students expressed this very clearly:

> "The first day I walked into Communications Technology, I had little, to no physics knowledge........................This all meant that I didn't feel too good about having to do a unit, which had a heavy emphasis on physics. But I soon found out, through discussions and experiments, that physics is interesting, relevant and easy to learn, but that might only be in Communications Technology!!!"

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TEACHING FOR UNDERSTANDING

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Teaching for understanding is one of a family of related reforms currently receiving serious consideration by teachers and researchers in the United States and elsewhere in the international educational community. In some other contexts it is called "active learning" (OECD, 1993), "adventurous teaching" (Cohen, 1988), "higher-level cognitive learning " (Tobin, Kahle & Fraser, 1990), and "teaching for the twenty-first century" (America 2000, 1991). In the context of school science, similar themes have been taken up in reforms built around the ideas of constructivism (von Glasersfeld, 1987) and children's science (Osborne & Wittrock, 1985; Pines & West, 1986). The notion of teaching for understanding "has been held up as a new standard for teaching practice – a goal towards which schools and the education profession should move" (McLaughlin & Talbert, 1993, p. 2). In America, it has been enshrined in national reforms in science education (American Association for the Advancement of Science, 1988) and mathematics education (National Council of Teachers of Mathematics, 1991).

Talbert and McLaughlin (1993) identify three core principles of teaching for understanding:

> (1) a conception of knowledge as *constructed* by the learner and therefore *situated* in the context of prior knowledge, skills, values and beliefs; (2) a conception of teacher as *guide*, as *co-constructor* of students' knowledge; and (3) a conception of the classroom as a *community of learners*, in which shared goals and standards, an atmosphere of mutual trust, and norms for behaviour support students in taking the risks and making the sustained efforts needed in serious learning" (1993, p. 169) (Italics in the original).

The purpose of this paper is to consider some of these ideas about teaching for understanding. The paper began, as so many papers do, with two colleagues trying to agree on the meaning of some empirical evidence they had collected. One of us, with a long history as a constructivist science teacher and researcher, had been evaluating the implementation of a new constructivist physics syllabus (Parker, Wildy, Wallace & Rennie, 1994). This project had thrown up two parallel cases of very experienced physics teachers who had noted significant falls in student performance as a result of early attempts to implement the new syllabus and pedagogy. For the first teacher, one such instance was enough to cause him to abandon the new approach; the other teacher was undeterred.

What we could not agree on was whether the coincidence of these two parallel cases ought to shake our faith in the idea of teaching for understanding. If these two fine teachers were having trouble, we wondered, what were we doing encouraging our colleagues and students to follow in their footsteps?

As we argued these and some other cases we both knew well, we had the uncomfortable experience of realising that we shared several areas of uncertainty about the practice of teaching for understanding, and we had many other equally worrying examples. This paper is a first attempt to organise our thoughts about what we don't understand about teaching for understanding.

Our attempts to understand teaching for understanding have left us with four unanswered questions which we want to share with you:

- Is "teaching for understanding" about the teacher's method or the students' learning outcomes?
- What kind of understanding does teaching with metaphors and analogies promote?
- Does specialist language interfere with understanding, or construct it?
- Whose understanding counts as understanding when students' performance is assessed?

Teaching for understanding: Method or outcome?

The two physics teachers whose teaching got us started on this line of inquiry both struggled to replace their didactic teaching practices with practices that paid more attention to providing opportunities for students to construct their own understandings.

One of them, David, is a veteran physics teacher working in a large secondary school which serves a poor suburban neighbourhood. As he explored the approach mandated by the new physics syllabus, he tried to help students to find their own ways of expressing their understanding of physics and to adapt his lesson plans to follow the students' learning. He deliberately paid less attention to time and content coverage and more attention to students' understanding.

For example, he began a Year 11 unit on sight and light by explaining to his students that he was "experimenting" with a new way of teaching physics and that he was not sure of its outcomes. In a lesson on Snell's Law (reported in Wildy & Wallace, 1994), he provided fewer than his usual number of instructions on how to complete the experiment, talked quietly with individuals and groups of students as they worked, asked students to interpret the results for the class, and expected them to write up their findings in their own words. On the few occasions when he spoke to the whole class, the purpose was to help students draw out the implications of their observations. His students noticed the difference in the lessons on sight and light, commenting that, "It's better than working from a text book. You get to understand because you're doing it".

At the end of the unit, however, David was disappointed that students' enthusiasm for the new approach was not reflected in their test scores. At first he "wondered if they'd learned anything at all", but he also wondered whether he had been successful in framing questions that would assess students' understanding and skills, rather than testing their content knowledge. Fortunately, David had the status and autonomy to continue teaching for understanding in the face of poor marks. He was a very experienced teacher, head of science in the school, a senior member of the State science teachers' association, and he was the only person teaching the physics course in his school.

Mr Ward is the name we have given to another Year 11 and 12 physics teacher who had a similar experience (Wildy & Wallace, in press). Mr Ward taught at an elite private girls' school, following the same State-wide mandated syllabus as David. Mr Ward had a strong academic background in physics and a long and successful record of preparing able students for the TEE. The quest for high TEE aggregate scores dominated Mr Ward's teaching and his students' learning during their final two years of school. When he taught, he had more than knowledge of physics on his mind. As he explained:

> The students don't necessarily want to study physics to do physics but to get into university ... They're not interested as much in physics as in their TEE aggregate. So everything that happens in class must bear directly on that. Anything else is seen as a wasteful digression. *We are all here to get good TEE results.*

Like David, Mr Ward's assumptions about the process and content of physics were challenged when the physics syllabus changed. Mr Ward, too, was willing to experiment with a more contextual approach to teaching physics. He taught the syllabus unit on sight and light using photography as a context, but he ran into problems. As he put it:

> You soon got lost in the complexity of photography. The principles of light came three or four days after we started so we had spent all of that time talking about things some of the students understood because they had some background in photography and others didn't. The end result was that none of them was particularly good at the basic ideas of light.

Mr Ward felt that when he "tried to be totally context based the structure of the subject disappeared". He was uncomfortable that he did not know where he was going, his students were disappointed with their lower than normal test scores, and he was concerned that he would not have time to cover the content of the course.

When Mr Ward had an experience similar to David's, of students receiving much lower than normal marks, he did not feel that he could keep on experimenting. In the context of an expensive private school and motivated students who were relying on high physics marks to get them into the university and course of their choice, one set of low marks was sufficient to lead him back to teaching for factual recall. For Mr Ward, the best measure of understanding was not the input variable of his teaching technique but the output variable of the students' examination success.

What kind of understanding do analogies promote?

When teachers use analogies to introduce and consolidate concepts, it may not always promote students' understanding. We illustrate this issue by reference to a vignette collected in the Year 10 general science chemistry class of a constructivist science teacher. She is committed to teaching for understanding, and often says to her students that "there are no right and wrong answers".

During a revision lesson she asked her students to "review the periodic table and sketch the configuration for hydrogen and carbon". Initially there seemed to be some confusion over the task. As one student said, "Why use the periodic table?" The students soon realised that the periodic table allowed them to see how many electrons there are for a given element. The teacher then asked a student to draw his sketches on the board. The sketch of hydrogen showed two concentric circles, an electron in the outer one and a "p" shown inside the inner one. The diagram for carbon showed six electrons in a single orbital. The teacher erased the inner circle on the diagram for hydrogen. When a student suggested that the electron configuration for carbon should be two electrons in the inner orbital and four electrons in the outer orbital, she changed the diagram to reflect this suggestion. After a few more blackboard drawings, the teacher asked the class, "How many electrons would hydrogen like in its orbit? Four house points if someone can explain why the answer is two." "Electrons don't like being by themselves" explained a student.

In this chemistry lesson, it is not clear whether the science she is teaching is about facts or metaphors. The teacher's willingness to redraw the diagrams of atomic structure suggests that she considers these diagrams are metaphors. But this view is contradicted by her willingness to award house points for some particular answers to her questions. Presumably, students would also be wiser to copy down the teacher's corrected diagrams in their notebooks than to trust that the test will allow for several different sets of notation.

But how clear is it whether the teacher's corrections really are more correct than the diagrams they replaced? In the case of the hydrogen drawing, the inner circle could have represented the boundaries of the nucleus, or it could have represented an empty orbital. Equally, what does it mean to represent electrons as being on orbitals? Do students understand it to represent a spatial difference, like the solar system, or paths of equal energy? Faced with questions like these, we sometimes think that school science is about passing on an authorised set of metaphors. Which metaphors count as "facts" depends more on whether the metaphor matches a teaching point that can be understood a particular Year level than whether the metaphor would be accepted by scientists currently working in the field. In about Year 6, for example, students often do an "experiment" involving celery sticks and beakers of coloured water. It is a common and memorable activity, a suitable Year 6 activity and at that level an authorised metaphor for the capillary action in plant nutrition or photosynthesis. In Year 12 biology, however, can photosynthesis be explained by the metaphor of celery and red water?

Does specialist language interfere with understanding, or construct it?

A key plank of the "teaching for understanding" platform is that students should construct their knowledge of science using the language and concepts they already know. This principle was at work in David's classroom, described above. We share David's belief that students' understanding will be enhanced when they use their own language to explain the phenomena they are learning about. We are sympathetic to his view that "too many students learn whole slabs of text and regurgitate them in texts and exams". We understand why, at the end of the lesson described in the vignette, he asked students to write about their findings in language that could be understood by any reader.

But we also wonder if there is a limit to this argument. Science does have its own language, its own discourse with distinctive forms of organisation and diction. Many of these discourse features go to the heart of science as a particular system of thought, with particular standards of evidence, argument and proof. To study science without learning to master these discourse forms would not be studying science as we know it (Lemke, 1985). Students who cannot master the structures and language of science text books will be cutoff from a significant source of understanding; students who cannot reproduce these textual forms run the risk of being misunderstood as not really understanding science. Even in primary schools, some people argue that it is essential for students to learn to master the forms of scientific discourse (Martin, 1990). Without the discourse, where is the discipline of science?

Mr Ward's approach seems closer to capturing the sense of science as a discourse which must be mastered. From the beginning of Year 11 he told students which material should be committed to memory, showed students how to create the "correct impression" for the external examiner at the end of Year 12, and justified his use of class time in terms of his experience of the content of the final exam.

Whose understanding counts as understanding when students' performance is assessed?

Teaching for understanding requires teachers to develop students' alternative formulations of physical phenomena and to be tolerant of students' imperfect understandings. This is OK in theory, but we wonder which understandings usually count in our current assessment regimes – students' provisional understandings or teachers' authorised understandings?

Unless and until teachers and examiners use assessment items that probe students' understanding – for example, of the theoretical implications of the spatial representation of Bohr's model of atomic structure – students are likely to be rewarded for the simpler skill of drawing it with the same number of orbitals as the teacher has in her mind. And what is in her mind will depend on her own understanding of science. This understanding will often have been developed twenty years or more ago when the teacher last studied science at university. For these two reasons, the tendency for understanding to be tested as facts and for the facts to have been learned a long time ago, we sometimes wonder whether Mr Ward's careful, explicit teaching of the facts is not more honest than pretending that "there are no right or wrong answers".

Conclusion

The conclusion we draw from these and other observations about the practice of teaching for understanding is not that teaching for understanding should be abandoned as a goal, but that there is much more to understand about making teaching for understanding work in science classrooms. In science education, much of the discussion on this topic over the past decade has centred on appropriate pedagogies. It seems to us that the reasons preventing improved student understanding in science have as much to do with contextual factors — schools, examinations, parents, scientific discourse — as they do with pedagogical factors. Perhaps this is what Talbert and McLaughlin (1993) mean when they refer to the importance of *situated* knowledge and shared goals. In any event, we argue here that teaching for understanding is more complex than first imagined. We believe that wholesale efforts to promote more satisfying and effective form of instruction should be approached with a degree of caution commensurate with the complexity of the reform.

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GETTING IT TO WORK: VISITORS' USE AND UNDERSTANDING OF THE WHISPERING DISHES AT AN INTERACTIVE SCIENCE CENTRE

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Introduction

Studies of learning in science education centres, science museums and interactive science centres (ISC) have aims which either focus on the exhibit or on the visitor, or both. Research focusing on visitors and exhibits has shifted focus from investigating what the exhibit does to the visitors, referred to as evaluation studies, to research investigating what visitors make out of exhibits (Miles, 1993). It is important to assess the performance of the exhibit in educational terms: how well did it communicate? Previous attempts to investigate learning at museums have produced no evidence of significant learning (Miles, 1986). Research in ISC has been conducted in Australia by Anderson (1994), Beiers and McRobbie (1992); Powe (1986) and Wanless (1990). Overseas research studies include Borun, Flexer, Casey and Baum (1983); Diamond (1986); Feher and Rice (1985); Friedman (1979); Gennaro (1981); Gottfried (1979); Balling, Cornell, Hilke, Liversidge and Perry (1985); Javlekar (1989); Koran and Koran (1983), Miles (1986) and Salmi (1993). Bitgood (1991) prepared a good bibliography for hands-on, participatory and interactive exhibits, and McClafferty and Rennie (1992) provide a review of learning in interactive science centres and science museums.

This study focuses upon the activities and the learning outcomes of the visitors to an ISC who interacted with the exhibit *Whispering Dishes*. The study uses qualitative and quantitative data collection methods (Miles, 1993) that work very well in an interactive science centre where the visitors interact and engage in a time frame ranging from 10 seconds to 10 minutes with the *Whispering Dishes*.

Description of Exhibit

The *Whispering Dishes* are two fibreglass parabolic reflectors of 2 m diameter mounted on platforms approximately 50 m apart. The dishes are aimed at each other and the exhibit has an objective of presenting sound wave reflection and focussing so that visitors can project their voice across the room to the other dish. The dish has a metal frame which is located at the focal point of the parabola where visitors either locate their ear to listen or their mouth to project. Visitors who are skilled in utilising the *Whispering Dishes* sometimes spend 2–10 minutes conversing with each other from one end of the gallery to the other.

The investigation described in this study deals with two aspects: firstly the activities of the visitors to get the exhibit to work and, secondly, the notions of the visitors about what this exhibit is doing when it projects their voice to the other side of the room.

Subjects and Method

The subjects for this study are 340 visitors, aged from 3 to 65 years, who visited an interactive science centre and interacted with an exhibit called the *Whispering Dishes*. The composition of the sample is shown in Table 1. The sample was obtained by observing visitors who mounted the platform on which the exhibit was located during weekend sessions at the centre. The gender composition of the sample was 58% male and 42% female. The observer was located in the nearby canteen with an unhindered view of the exhibit on a nearby platform. The observer's presence was disguised by sitting at a table amongst visitors enjoying a break from the activities occurring within the gallery. The age of the visitor was estimated and, if the visitor was successful, later checked during the questioning. Activities of visitors were recorded on a score sheet (Interaction Instrument) as they attempted to get the exhibit to work. If the visitor was successful and communicated to another visitor, the visitor was briefly questioned before leaving the *Whispering Dishes* platform. All visitors cooperated, however the visitor's manner suggested that they would answer only brief questions as they did not want to delay their interaction with other exhibits.

Table 1
Sample composition

Visitors (n=340)	Age groups					Total
	3 – 6 yrs	7 – 10 yrs	11 – 14 yrs	15 – 34 yrs	35 – 65 yrs	
Males	36	50	30	31	49	196
Females	24	33	21	41	25	144

The observer recorded on the Interaction Instrument if the visitor (a) mounted the platform to attend to the *Whispering Dishes*, (b) looked at the nearby exhibit label, (c) touched the exhibit, (d) attempted to whisper, speak or listen at the focal point, (e) explored the exhibit, (f) experimented by repositioning their mouth or ear at the focal point, or increased their voice projection (shouting), and/or (g) communicated to another using the exhibit. An exhibit interaction was recorded as successful if the visitor was able to communicate to another on the other side of the gallery. This was readily noticed by direct observation of the visitor. Successful visitors were interviewed on leaving the platform and asked four questions:

1 "How old are you?"
2 "Have you visited here before and used the Whispering Dishes?"
3 "You use the Whispering Dishes very well. Can you tell me how you learnt to use the Whispering Dishes? (Sometimes visitors were prompted with.... Do you read the signs, watch others, or were you taught by someone?")
4 "Can you tell me how the Whispering Dishes work? How could you hear others on the other side?"

Results

Results for all visitors

The visitors who mounted the platform can be broadly classified into three groups: Firstly, the group who failed to engage with the exhibit. Engaging with the exhibit is attempting to get it to work and is usually observed by the visitor positioning their mouth or ear near the focal point of the dish. These visitors mounted the platform, looked at dish, occasionally looked at the label, may have looked to see if there was another visitor on the other platform with which to communicate, and then departed from the platform. Secondly, the visitors who engaged with the exhibit but were unsuccessful in attempting to get the exhibit to work. These visitors failed to position their mouth or ear in the correct location of the focal point, or whispered too softly or may have had a hearing impairment. Thirdly, the visitors who engaged successfully, and many engaged in protracted conversations. The percentage of visitors for each age cohort of these three groups is shown on Table 2.

Table 2 shows that about half of all visitors, both male and female, are able to get the *Whispering Dishes* to work successfully, ie., they were able to communicate with another visitor at the other side of the gallery. This success rate of near 50% for the exhibit is very good overall for the total of all visitors (48% Male and 49% Female). The success rate increases with the first two cohorts of 3–6 yrs and 7–10 yrs, and then does not increase with the maturity of the visitors. The most successful are visitors above the age of 11 years regardless of gender. Two groups fall amongst the unsuccessful. The very young of 3–6 yrs where boys perform poorly and adult females of 35–64 yrs where 44% fail to interact.

The exploratory behaviour of visitors is shown on Table 3. Young children in the 3–6 years cohort displayed the greatest exploratory behaviour. Young children crawled into the steel frame on the dish and regularly looked behind and underneath the dish. This behaviour quickly diminishes as the age of the visitors matures. However the behaviour occurs for a longer period with males, and at a higher rate of occurrence with males being twice more likely to engage in the behaviour.

Table 2
Percentage of visitors' engagement and success

Visitors	Age groups					Total
	3- 6 yrs	7 – 10 yrs	11 – 14 yrs	15 – 34 yrs	35 – 65 yrs	
			Failed to engage (n=104)			
Males	53%	24%	18%	29%	29%	30%
Females	38%	21%	29%	32%	44%	32%
			Engaged unsuccessfully (n=71)			
Males	31%	14%	23%	13%	14%	22%
Females	25%	33%	14%	15%	8%	19%
			Engaged successfully (n=165)			
Males	17%	48%	63%	58%	57%	48%
Females	38%	45%	57%	54%	48%	49%

Table 3
Percentage of visitors displaying exploratory behaviour of each age group

	Age groups					Total
	3–6 yrs	7–10 yrs	11–14 yrs	15–34 yrs	35–65 yrs	
Males	14%	12%	10%	6%	4%	9%
Females	17%	3%	5%	2%	0%	5%

Results for successful visitors

The results of questioning 165 successful visitors to determine if they were repeat visitors, to determine how they learnt to use the exhibit and their understanding of how the exhibit worked are shown in Tables 4, 5 and 6. Table 4 shows the percentage of repeat successful visitors averaging 42% for males and 24% for females. Some visitors, especially young boys of 11–14 years, are repeat users of the exhibit and represent 63% of their cohort. Females are under represented in most cohorts of repeat users.

Table 4
Percentage of successful visitors who are repeat visitors to exhibit

Visitors	Age groups					Total
	3–6 yrs	7–10 yrs	11–14 yrs	15–34 yrs	35–65 yrs	
Males	33%	46%	63%	39%	29%	42%
Females	33%	40%	17%	18%	17%	24%

The reading of text and graphics by visitors is of importance to novice (first-time) users of the exhibit. Table 5 for successful visitors shows that females are more likely to be readers of text and graphics than males by a factor approaching 2. The average male visitor's reading of labels is 4%, whilst the female average is 7%. The young cohorts of 3–6 years and 7–10 years are not good readers of text and interpreters of graphics, however they are good observers. Children in these two cohorts learn how to use the exhibit either being taught by another visitor who already knows the technique, or the children observe other visitors using the exhibit. Children's most common method for learning how to use the exhibit is to be instructed by others. Some visitors did not read, observe others, or were instructed. These visitors said that they knew how to use the exhibit by looking at it, and had an idea on how it worked. This method of learning was referred as being intuitive and occurred with adult males of cohorts years or older.

Successful visitor's understanding of the exhibit

The final question for successful visitors aimed to investigate the comprehending of the exhibit by visitors and what the visitors were making out of the *Whispering Dishes*. The visitors were asked the short question, "Can you tell me how the *Whispering Dishes* work?" The responses were short and were classified into approximately six categories and the results are shown on Table 6.

Table 5

Percentage of successful visitors with method for learning how to use exhibit

Visitors	Age groups					Total
	3 – 6 yrs	7 – 10 yrs	11 – 14 yrs	15 – 34 yrs	35 – 65 yrs	
Read labels and looked at graphics						
Males	0%	16%	40%	73%	64%	44%
Females	25%	30%	50%	82%	90%	64%
Observed others						
Males	25%	32%	47%	13%	0%	20%
Females	50%	40%	25%	6%	0%	18%
Instructed by others						
Males	75%	52%	13%	0%	18%	26%
Females	25%	30%	25%	0%	10%	14%
Used Intuition						
Males	0%	0%	7%	14%	18%	10%
Females	0%	0%	0%	12%	0%	4%

Three categories deal with the aspects of the concept "sound" within a simple hierarchy of (a) waves, which is one aspect; (b) reflection of waves, with two aspects of waves and reflection; and (c) the focusing of the wave by the parabolic dish, having three aspects of waves, reflection and focus. Three further categories were used for responses of visitors who (d) responded with the instructions on how to use the Whispering Dishes or (e) provided a misconception, or (f) said they did not know how it worked. Examples of these responses for the different categories will be provided in the discussion.

Table 6

Percentage of successful visitors' understanding of the exhibit

Visitors	n	Understanding					
		Waves	Waves & Reflection	Waves, Reflection and Focusing	Described Activity	Mis-conception	Unknown
Males							
3 - 6 yrs	6	0%	0%	0%	17%	33%	50%
7 – 10 yrs	24	13%	8%	0%	8%	4%	67%
11 – 14 yrs	19	21%	26%	5%	0%	26%	22%
15 – 34 yrs	18	6%	11%	44%	0%	6%	33%
35 – 65 yrs	28	0%	7%	43%	4%	0%	46%
Males	95	8%	11%	19%	6%	14%	42%
Females							
3 – 6 yrs	9	11%	0%	0%	11%	0%	78%
7 – 10 yrs	15	13%	0%	0%	20%	7%	60%
11 – 14 yrs	12	17%	25%	0%	0%	8%	50%
15 – 34 yrs	22	14%	9%	5%	9%	0%	63%
35 – 65 yrs	12	0%	8%	17%	8%	25%	42%
Females	70	11%	8%	4%	10%	8%	59%
Total	165	10%	10%	13%	7%	8%	52%

Discussion

Visitor interaction and engagement

This study has looked closely at the behaviour and the comprehending of the *Whispering Dishes* exhibit by visitors at an interactive science centre. The first part of the study investigated the behaviour of 340 visitors and what they did as they interacted with the exhibit. Exhibit designers want visitors to read the exhibit labels and interact successful with the exhibit. Higher cognitive outcomes of comprehending and learning associated with the phenomena the exhibit is attempting to present is not necessarily articulated by the exhibit designers. Exhibits are designed with the hope of visitors interacting and achieving the appropriate behavioural outcomes, however few designers have articulated appropriate cognitive learning outcomes for the exhibit. For example, the objectives for the Sound Dishes at the Science Museum, London are:

- To demonstrate the principle of parabolic reflectors,
- To demonstrate sound transmission, and
- To develop teamwork and co-operation, communication and testing (various levels of sound).

These objectives are not operationally defined, and require further analysis to provide the objectives with more detail.

In the case of the Whispering Dishes, Tables 2 and 6 show that for the 340 visitors who mounted the platform to interact with the exhibit, only 165 visitors were able to achieve the behavioural objective of getting the exhibit to work, and of these 165 visitors there were 55 (33%) who had an understanding that the exhibit works by sound waves. More important are visitors who interacted successfully and had no idea how the exhibit worked (52%), and visitors who answered with misconceptions (8%). These visitors are using the machine and not necessarily gaining cognitive knowledge about the concept "sound".

One reason for the failure of visitors can be attributed to the need to have another visitor on the other side to interact and the lack of skill in using the exhibit. The data in Table 2 shows that the two main cohorts that failed to interact with the exhibit are the very young (3–6 years) and the senior group of (35–65 years) of females. The very young are only just learning to read, and many learn to interact by being instructed by others or by observing other visitors. The female senior cohort's poor performance may be explained in terms of how they perceive their role during the visit, a role which has been referred to as the visitor's agenda (Falk & Dierking, 1992). Most senior visitors come as parents or grandparents with a family grouping and may see their agenda during the visit as a chaperone and not to explore and interact with the exhibits.

In an evaluation by Creative Research Ltd (1993) of the Launch Pad at the Science Museum, London, visitors were asked to identify exhibits from which they felt they learnt the most. The two highest scoring exhibits were the *Sound Dishes* and the *Turntable* and these exhibits were mentioned in 6% of the responses. The exhibits visitors felt they learnt most from tended to coincide with those exhibits which visitors felt they had enjoyed the most. This evaluation identified a series of factors associated with popular exhibits. These factors are (a) teamwork and co-operation, (b) familiarity and fun orientated, (c) novelty, and (d) problem solving and collaborative activity (putting it together as a group).

Exploratory behaviour and experimental behaviour was displayed by some of the visitors who used the *Whispering Dishes*. This experimental behaviour was displayed by visitors using differing voice levels of shouting and whispering to enable communication to the other dish. This behaviour of testing and manipulating the variable of voice level is important for the visitor to understand the operation of the Whispering Dishes. Feher (1990) reports on the important activity of the visitor to "go messing about", like Toad in *The Wind in the Willows* (Feher, 1990). Here, the visitor plays around, explores and manipulates the exhibit to gain an understanding of how the exhibit is intended to operate. This notion of the visitor messing about in science has earlier been suggested also by Hawkins (1965/1992) and is evident within other epistemological frameworks, see for example Polanyi's vision of a society of explorers and Poincaré's period of play and experimentation (Gelwick, 1978).

Visitor understanding of the exhibit

Beiers and McRobbie (1992) have investigated, using phenomenography, children's understanding of the aspects of the concept "sound" at an interactive science centre. They state that a prominent feature of research on children's learning in science has been the important role of the prior knowledge that children bring to the learning situation. This may be extended to the wider population of adults. Beiers and McRobbie found that children who already had the concept of sound as a vibration or wave were most likely to have made major changes in their levels of understanding towards the scientifically accepted view relating amplitude and wavelength to different sounds. The understanding of *Whispering Dishes* requires knowledge and understanding of waves, and if this aspect is understood then the other aspects of reflection and focusing may be achieved by the visitors. This was evident in the responses of the visitors describing how the exhibit worked. The visitors' responses were in terms of waves; or waves and reflection; or waves, reflection and focusing. Very few visitors mixed the aspects within these three categories. For example, a typical wave response was, "Well...it's hard to explain...the sound waves go from this dish to the other dish". The typical wave and reflection category response was "I say that the sound waves reflects off the satellite dish", and the typical response for focusing, reflection and waves was "It's basically focussing your sound wave to a very narrow point and bouncing it across to the other side to the other dish, which picks it up and re-intensifies the sound so that you can pick it up at the other end."

Knowledge hierarchies have been suggested as an important criteria in determination of exhibit effectiveness and a method for measuring learning at a museum exhibit (Perry, 1993). The knowledge hierarchy assessment technique is based on the assumption that inherent in each exhibit is an internal knowledge structure. This knowledge structure is at the intersection of the exhibit developer's and the visitor's, organisation and understanding of the topic. A knowledge hierarchy is simply a description of this range of understanding. From this study of the *Whispering Dishes* a six level knowledge hierarchy was developed after analysis of the visitor's responses:

0 No awareness or interest in how the sound was being projected across the room.
1 An explanation, but incorrect (misconception),
2 An explanation of what you had to do, but not how it operated,
3 An understanding that sound or sound waves travelled across the room,
4 An understanding that sound waves were reflected from the dish across the room,
5 An understanding that sound waves were reflected across, focussed and heard by the partner's ear at the focal point.

Perry suggests the development of a knowledge hierarchy for an exhibit and its use in subsequent summative, front-end and formative evaluations. During this process, a series of carefully worded interview questions can be used to determine where a particular visitor is placed on the hierarchy. Boykoff and Hogan (1987) suggest that ISC play an important role in teaching the visiting public science concepts and thinking skills. These skills have been described as working scientifically in the National Science Statement and relate to the activities of the visitors manipulating, exploring and experimenting with the exhibits. In the *Whispering Dishes* some visitors attempted to use the exhibit with differing voice levels. Some visitors shouted into the dish, whilst other whispered. Visitors were experimenting with the exhibit manipulating one variable, sound level.

Comments of the repeat visitors illuminate the processing of information gained by using the *Whispering Dishes* and similar exhibits at other locations. For example, "We went to this airport [Changi] and saw this saucer thing, and my Dad and me talked to each other. I went on this side and he went on the other side, and we talked. Well, there's got to be another person to talk to and hear what you have to say. Because it's got electricity and goes into the leads, comes through the ground and goes right to that other thing" (6 year-old boy). This visitor was convinced that he knew how the exhibit worked, however visitors often interpret their observations in unexpected ways. These alternative conceptions have been previously noted in science centres by Feher (1990) and Beiers and McRobbie (1992). Other visitors relate the exhibit to similar exhibits and a few responded describing how they understood the *Whispering Dishes* by previously using the *Whispering Walls* of the cupola of St Peter's in the Vatican and St Paul's London.

Conclusion

Visitors to interactive science centres come to these institutions to enjoy the exhibits and each other's company, and any learning is subsidiary to these maxims. It is important for the curators and exhibit designers to have articulated the cognitive and behavioural objectives for the exhibit. In this study the cognitive and behavioural objectives for the exhibit *Whispering Dishes* had not been defined. A six level knowledge hierarchy was developed for the *Whispering Dishes* after analysis of the visitor reponses. Further behavioural analysis to investigate visitors 'messing about' as they experiment and explore the exhibit will be the subject of a later paper.

This study has highlighted two important groups who interacted with the exhibit. One group enjoyed the success of getting the exhibit to work. What of the other group? This group, like the successful group, interacted and attempted to get the exhibit to work to no avail. They probably did learn something during their activities, and may on another visit to a centre get a similar exhibit to work for them. What did they learn? Both groups learned skills as they went "messing about with science" like Toad in the *Wind in the Willows.*

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STUDENT MISCONCEPTIONS OF DIFFUSION AND OSMOSIS

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Introduction

Misconceptions are extremely common in science partly due to the abstract nature of the concepts to be learned in combination with the concrete reasoning ability of most secondary school students (Garnett, Tobin & Swingler, 1985).

Biology contains many abstract concepts with unobservable attributes. For example, the processes of osmosis and diffusion can only be comprehended by students if they can construct an accurate mental representation of the behaviour of the unobservable particles that comprise matter. Research has elicited frequent, fundamental misunderstandings about the motion and spacing of particles (Novick & Nussbaum, 1981).

Diffusion and osmosis are foundation concepts necessary for a sound understanding of many plant and animal physiology topics. In Western Australia the concept of diffusion is included in several lower secondary science units. Diffusion and osmosis are integral to the Year 11 and 12 Biology and Human Biology syllabi. These concepts relate specifically to cell transport, cell membrane function, internal transport systems, digestion, excretion and water balance, gas exchange and cell responses to various water solutions (Secondary Education Authority, 1991).

Previous research indicates that Scottish students rate osmosis, water potential and water balance as the most difficult topic in matriculation biology (Johnstone & Mahmoud, 1980a). Pencil and paper tests (Marek, 1986; Simpson & Marek, 1988; Westbrook & Marek, 1991) reveal that students have great difficulty explaining diffusion in molecular terms. Interviews of small numbers of 14-17-year-olds (Friedler, Tamir & Amir, 1985; Johnstone & Mahmoud, 1980b) revealed misconceptions of osmosis and osmotic potential.

Research Questions

1. What are Year 12 biological science students expected to understand about diffusion and osmosis?
2. What level of understanding do Year 12 biological science students have about diffusion and osmosis?
3. What misconceptions of osmosis and diffusion can be identified in a sample of Year 12 biological science students?

Methodology

The objectives of the Year 11 and 12 Biology and Human Biology syllabi (Secondary Education Authority, 1991) were analysed to determine what understanding of diffusion and osmosis was expected from students at the completion of their courses.

A concept map was constructed based on those objectives. A set of propositions defining the knowledge of diffusion and osmosis required by students of Biology and Human Biology was prepared based on the concept map. These propositions (Appendix 1) were appraised and validated by two science educators from a Western Australian university. An interview schedule was developed to probe students' understandings of these propositions using an interview-about-events methodology
(Osborne & Cosgrove, 1983).

The propositions defining the knowledge required for a sound understanding of osmosis and diffusion were used to identify eight concept areas for investigation. A series of four events, shown in Table 1, were incorporated into an interview schedule that was used to probe students understanding of the concepts.

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Table 1.
Events used to probe understanding of selected concept areas

Event		Concept areas investigated
1.	Glass of water	Particle theory Kinetic theory of matter Evaporation Diffusion
2.	Sugar cube in a glass of water	Particle theory Kinetic theory Dissolving Concentration difference Diffusion
3.	Dry sultanas and sultanas soaked in water	Kinetic theory Concentration difference Cell theory Diffusion Osmosis
4.	Red blood cells in water, plasma and salt solution	Kinetic theory Concentration difference Cell theory Diffusion Osmosis

The sequence of events was designed so that general concepts, such as particle theory and kinetic theory, were investigated before the more specific concepts of diffusion and osmosis. This aspect of design was incorporated to allow the researcher to identify the apparent basis for misconceptions of diffusion and osmosis.

Events 1, 2 and 3 were illustrated using actual examples of a glass of water, sugar cube, dry sultanas and sultanas distended through soaking in water. In Event 4, students were presented with a drawing of a red blood cell as it appears in blood plasma. Students were asked to draw how a blood cell would appear after being in pure water and a concentrated salt solution for some time.

Subjects

Eighteen Year 12 Biology and Human Biology students were selected from a Perth metropolitan senior high school. Nine students were selected from each of Biology and Human Biology. The students were selected from four different classes. Each class had a different teacher. A stratified sampling technique was used to select students. Each subject area supplied two A grade, three B grade and four C grade students. Approximately equal numbers of male and female students were selected.

Data Analysis

Data from the interviews were in the form of audio recordings and completed record sheets. The audio recordings were coded according to the level of understanding demonstrated for each of the knowledge propositions. For each proposition, student understanding was coded as either sound understanding, incomplete understanding or misconception.

Sound understanding was defined as an explanation of the phenomenon which was scientifically correct and described the molecular basis of the processes. Incomplete understanding was defined as an explanation which showed that the student was unsure about the processes occurring or offered only partial scientific reason for the phenomenon being discussed. When the student offered an explanation that was not scientifically correct, it was coded as a misconception. Table 2 indicates the percentages of students responding in each category.

Results

Table 2.

Percentage of responses indicating sound understanding (SU), incomplete understanding (IU) or misconceptions (M) of the propositions

	Proposition[a]	SU	IU	M
1.	Matter is composed of particles	83	17	0
2.	Particles are in continuous motion	44	28	28
3.	The motion of particles is in random directions	22	17	61
4.	Heating particles causes them to move faster	17	67	17
5.	Solvents are liquids that dissolve other particles	78	22	0
6.	Solute particles dissolve in a solvent	78	22	0
7.	Solute and solvent together make a solution	100	0	0
8.	Water is the solvent in living things	56	44	0
9.	Common solutes in living things are ions, oxygen, glucose and carbon dioxide	17	83	0
10.	The amount of solute dissolved in solvent is the concentration	100	0	0
11.	Random motion moves solute particles through the solvent	0	33	67
12.	Diffusion occurs when random motion causes nett movement from an area of high to an area of low concentration	22	50	28
13.	Diffusion is slow and only effective across short distances	0	100	0
14.	Rates of diffusion can alter with changes in concentration, particle size, membrane thickness, temperature and surface area	0	89	11
15.	Rate of diffusion slows as as concentration difference gets smaller	0	100	0
16.	Random motion eventually creates even particle distribution in solution	0	44	56
17.	Cell membranes are semipermeable	50	50	0
18.	Semipermeable membranes allow some substances through but not others	61	28	11
19.	Cell membranes allow water and small solutes to pass through	17	55	28
20.	Particle size relates inversely to the speed of particle motion	22	56	22
21.	Osmosis is diffusion of water from a high to low concentration through a semipermeable membrane	22	50	8
22.	Outward nett water movement occurs from cells in solutions containing higher concentrations of solutes	11	44	5
23.	Inward nett water movement occurs in cells in solutions containing lower concentrations of solutes	50	22	28
24.	Large nett water intake can cause an animal cell to burst	39	33	28
25.	Nett water loss causes the membrane to shrink inwards	22	67	11

Note. [a] The propositions listed here are abbreviated forms of the ones presented in Appendix 1.

Twenty-one different categories of misconception were elicited. Fifteen of these categories relate directly to the notion of non-random particle movement. Students tended to attribute the behaviour of solute particles to causes other than independent, random particle motion. A total of six different causes of particle motion were provided by students to explain the phenomena they had observed. These are listed in Table 3.

Table 3.
Categories of misconception in which students attributed various causes of non-random particle motion

Cause of particle motion		Related categories of misconception and their frequencies
1.	An external force	11c(17%) 16b(28%) 21a(22%)
2.	The movement of the entire body of matter	2a (22%) 3a (28%) 11a(39%)
3.	To create an equilibrium concentration	3b (17%) 11b(28%) 21b(17%)
4.	The particles are alive	3c (11%)
5.	Movement is towards an area where there is more room	16a(28%) 21c(17%)
6.	Movement is due to the needs of cells	16c(22%) 19c(28%)

Discussion

Student conceptions of particle and kinetic theory; dissolving, concentration difference and solutions; and diffusion and osmosis are discussed in this sequence as the earlier conceptions provide a foundation for understanding the later concepts.

Particle and Kinetic Theory

A large proportion of the Year 12 students interviewed in this study demonstrated acceptable understandings of matter being composed of submicroscopic particles. No misconceptions were elicited regarding this proposition and, as shown in Table 2, only 17% had incomplete levels of understanding.

Misconception of continuous particle motion in random directions were common. Less than 50% of the students interviewed could explain that particles were continually in motion. Incomplete understanding of this process was demonstrated by 28% and a further 28% held misconceptions.

Almost all of the students with misconceptions of particle motion thought that particles did not move independently. Students believed that particles would move only if the entire body of matter was moving. This point of view appears consistent with a concrete operational understanding of the motion of particles, where the student has failed to conceptualise the action of the unseen particles. In this study, students believed that particles of water move only when the water in the glass was moved.

The concept of particles moving in completely random directions (Proposition 3) appears to be a significant area of difficulty for many of the students. Sixty-one percent of students had misconceptions of this proposition. Five students (28%) felt that particles would only move in the direction that the entire body of matter was moving. Three students (17%) felt that particles would move in a particular direction in order to establish an equilibrium concentration or to occupy an area where there was "more room". This type of misconception reflects an anthropomorphic view of the world where particles are imbued with human characteristics in deciding to move in a particular direction to achieve some purpose (Gilbert, Osborne & Fensham, 1982).

Probes of Propositions 2, 3, 11, 16, 19 and 21 revealed six common unscientific explanations of causes of particle motion which are summarised in Table 2.

Similar findings have been reported in the science education literature. Friedler et al. (1985); Novick and Nussbaum (1981) and Westbrook and Marek (1991) have all reported that students hold misconceptions about the concepts of constant motion and random movement. Shepherd and Kenner (1982) stated that only five percent of North American senior high school students held sound conceptions of the kinetic theory of matter. It would appear from the literature that student misunderstandings about particle and kinetic theory are frequent, significant and international.

Dissolving, Concentration Difference and Solutions

The concepts of solute, solvent, solution, concentration, water as a solvent for life processes and common solutes in living organisms were all investigated during student interviews. No student held misconceptions of any of these ideas (Propositions 5-10). Relatively low frequencies of incomplete understanding were demonstrated for these concepts, indicating that these were not areas of difficulty for students. It was only when the notion of random molecular movement was investigated in relation to these concepts that students were found to have difficulty.

Research into student understanding about dissolving and concentration has elicited common misunderstandings about the molecular basis of solutions (Friedler et al., 1985), solvent and dissolving (Comber, 1983). Student misconceptions of these concepts were mostly evident where understanding was probed in relation to the random motion of particles.

The process of dissolving is dependent upon the random motion of particles across an area of concentration difference so that eventually, particle distribution will be even. If students do not fully comprehend the phenomenon of random motion it is logical that they could not fully understand the process of dissolving. Consequently, the process of diffusion in living organisms can not be fully understood as this is dependent upon the random motion of dissolved particles in solutions.

Diffusion and Osmosis

Although 72% of students were able to define diffusion and osmosis at least partially, most were unable to explain the molecular basis of the two processes or incorporate random motion into their responses. Difficulty was experienced when students were asked to apply an understanding of these processes to explain or predict what would occur in different biological instances.

Not one of the students interviewed held sound understanding of Propositions 13, 14, 15 or 16. These statements described aspects of the molecular nature of diffusion. The inability of students to conceptualise the molecular basis of diffusion has also been described by Marek (1986), Simpson and Marek (1988), and Westbrook and Marek (1991). These authors have attributed lack of understanding of the abstract nature of the process of diffusion to the concrete operational status of the subjects interviewed.

Student conceptions of osmosis are also limited by lack of understanding of the abstract conceptions of continuous and random particle motion. Friedler et al. (1985) investigated the understanding of osmosis by Year 9, 10 and 11 Israeli school students. They found 32% of the sample explained that molecules were randomly distributed in a solution. Significant misconceptions were reported regarding molecular movement and osmosis. As in this study, Israeli students provided anthropomorphic and anthropocentric conceptions of both particles and processes, that is, to attribute human characteristics to particles and explain processes in terms of personal experiences.

It is clear in both the literature and this study, that processes not readily observed by students are not fully understood. The concepts of continuous particle movement, particle motion in random directions, and particle movement which is independent of motion of the body of matter are abstract ideas which are poorly understood by the student population.

Results indicate that lack of understanding of continuous and random particle motion is responsible for the frequent student misconceptions of the molecular basis of the processes of diffusion and osmosis. It is speculated that the basis of misconceptions include the concrete operational status of the sample population, lack of concrete representations, poor explanations of the processes by teachers and lack of personal experience dealing with the concepts.

Summary and Conclusions

The knowledge deemed necessary for a thorough understanding of diffusion and osmosis was defined as a sequence of propositions. Student understanding was investigated using an interview-about-events methodology.

Three concept areas were identified in which greater than 50% of students demonstrated sound understanding. These included the concept of matter being composed of particles, the concept of a semipermeable membrane, and the related concepts of solvent, solute and solution.

Significant levels of misconception were evident in relation to 10 of the 25 propositions investigated. Almost all misconceptions were based on poor understanding of the random nature of particle motion.

It is clear that students do not consider the motion of particles to be continuous, in random directions or independent of the direction of movement of the body of matter. Instead, particles are often seen as moving to achieve some purpose, such as the establishment of equilibrium.

Common misconceptions of particle motion were:

- particles only move when the entire body of matter in which they are contained, moves;
- particles move in particular directions in order to establish an equilibrium concentration throughout the body of matter;
- particles move in specific directions due to some external force;
- particles move to areas where there is more room;
- particles move to satisfy the requirements of cells; and
- particles move because they are alive.

This research indicates that student misconceptions about diffusion and osmosis have their basis in misunderstandings of particle motion and kinetic theory. The possible origins of these fundamental misconceptions are many and varied. The unobservable nature of particles and their behaviour is likely to be a significant barrier to meaningful learning. The development of interactive multimedia materials that can represent particle motion using dynamic computer graphics should be given high priority.

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Appendix 1

Propositions defining the knowledge of osmosis and diffusion expected of Year 11 and 12 Biology and Human Biology students

1. Matter is composed of particles called atoms or molecules and the empty space between them.
2. Particles are continually in motion.
3. The movement of particles in gases and liquids is in random directions.
4. Heating particles increases their kinetic energy and causes them to move more rapidly.
5. Liquids in which other kinds of particles can dissolve are known as solvents.
6. Particles which dissolve in a solvent are known as a solute.
7. Particles of solute and solvent together are known as a solution.
8. In the world of living things, water is the solvent in which many other kinds of particle can dissolve.
9. In the world of living things, oxygen, carbon dioxide, ions, glucose and amino acids are common solutes.
10. The amount of solute dissolved in a certain amount of solvent is known as its concentration.
11. The random motion of solute particles enables them to move throughout the liquid.
12. Diffusion occurs when particles move in all directions by random motion, the nett movement of particles is from a region of high concentration to a region of low concentration, across an area of concentration difference.
13. Diffusion is a slow process and is only effective over short distances.
14. Increased temperature, increased concentration difference, smaller particle size, reduced membrane thickness and increased membrane surface area all act to increase the rate of diffusion.
15. The rate of diffusion will slow down as the concentration difference becomes smaller until the concentration is the same throughout the solution.
16. Movement of solute particles through a solution due to random motion in all directions will eventually cause nett particle movement to be zero and the distribution of the solute to be even through the solution.
17. A cell membrane is an example of a semipermeable membrane.
18. A semipermeable membrane will allow the passage of some things through it but not others.
19. Cell membranes will generally allow water and small solute particles to pass through them.
20. The size of diffusing particles effects the speed of the moving particle and the rate at which it can diffuse across cell membranes. Smaller particles move more rapidly and diffuse through membrane pores more easily than larger particles.
21. The diffusion of water particles across a semipermeable membrane from a region of high concentration of water to a region of low concentration of water is known as osmosis.
22. Outward nett movement of water from the cell will occur if the cell is in a solution containing a higher concentration of solutes than the cell.
23. Inward nett movement of water will occur if the cell is in a solution containing a lower concentration of solutes than the cell.
24. A large nett intake of water into an animal cell may cause the cell membrane to burst.
25. Nett loss of water from the cell will cause the membrane to shrink inwards.

THEORY, ETHICS AND POLITICS: INTERPRETIVE RESEARCH IN SCIENCE EDUCATION

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Introduction

In this paper, we consider the role of theory, ethics and politics in interpretive research and focus our discussion on the evolving interpretive framework of Cath's doctoral study of cultural myths in the science classroom. In constructing this framework, Cath is seeking to gain insight into how myths develop, how myths have been identified and interpreted by other researchers, and how others have described the role of myths in society. Her interpretation of other people's research and theorising constitutes a synthesis of the literature (traditionally called a 'literature review') and is assisting her to construct an interpretive framework for a subsequent analysis of classroom discursive practices in school science. During this self-reflective process, Cath is considering how her study is to be legitimated. In this respect, she is examining the relationship between ethics, theory and politics in interpretive research.

Organising Components of Interpretive Research

In their recently published handbook of qualitative research, Denzin and Lincoln (1994) talk about qualitative research paradigms that are composed of principles about ontology, epistemology and methodology. Ontology encompasses the theoretical framework of the researcher; epistemology the research questions; and methodology considers how the questions will be examined. However, as Cath reflects on her own research she realises that ethics and politics have an equally important role to play in the conduct of her research. Ethics concerns the relationship between our personal values and the research that we are conducting, and politics concerns how our research is legitimated. Although ethics has come out of the closet and is now being discussed explicitly by educational researchers, we believe that the politics of legitimation continues to be an implicit component of most research in science education.

The Politics and Theory of Research (or How is My Research Legitimated?)

In the past, a common practice in science education research was to write of investigations in a way that assumed that the language used by the researcher was transparent (Foucault, 1974). The assumption was made that the purpose of the language of a research report was to convey the data but that the language per se had no influence on how the data were interpreted. In other words, it was assumed that the data 'spoke for themselves'. One of the outcomes of this assumption about the neutral role of language in the communication of data was the promotion of the use of seemingly non-emotive language in order to distance the researcher from the data. In science education research, it seems that little thought has been given to how language is used artfully (but unwittingly) to convince other researchers of the significance of data and of the appropriateness of interpretations that are generated from the data. That is, the rhetorical nature of research reports remains largely unexamined.

Research, Title and Narrative

Cath is writing her thesis as a narrative that consists of a beginning, a middle and an end, as do most stories. Although her written thesis implies an orderly progression of thinking from one chapter to the next, this organisational structure does not reflect the way that her ideas developed. Indeed, at times she worked concurrently on up to three chapters. The development of order in the presentation of her ideas required a cyclical approach to her research material so that the ideas that she was developing were mulled over and revisited many times.

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The narrative could be described also as composed of a title and a body. The body consists of many separate sections all of importance to the development of Cath's literature synthesis. However the title is very significant also because it acts as the signpost that highlights some of the significant features of the narrative.

Sociologist Joseph Gusfield (1976) first alerted her to the theoretical and political importance of the title of her thesis. She mulled over the title because it is a most powerful tool for providing immediate recognition to the target audience and is the starting block for the political process of legitimation. She uses the title also to inform her intended audience about her theoretical framework. For Cath, it is very important to ensure that the title is consistent with the methodology of the study so that there is a concordance between the audience's initial interpretations of her theoretical framework and the actual theories she used and developed in her doctoral study. The title that she has crafted (at this stage) is: *Socio-cultural myths and the science classroom: A critical analysis of discursive practice.*

From this title, she is making a political statement to the target audience which, she hopes, will recognise immediately that the accompanying presentation is based on significant research that warrants being considered seriously. If she was addressing a different audience, then she might have entitled the paper differently. For example, *Tall tayles and true: Messages from beyond the whiteboard*, if she was writing an article that was attempting to be amusing, or *Odysseus meets Wyatt Earp*, if she wanted to be obscure in a literary classical way. These alternative titles might be appropriate if she wanted to have extracts of her thesis accepted for publication in *The West Australian* or *The Australian* or, perhaps, in *The Practising Administrator*. However, because she is aiming for acceptance by the community of science educators, she attempts to ensure that her title identifies that group as her preferred audience. In this sense, the crafting of the thesis title was a political decision.

The title also indicates to readers something about the nature of the narrative of the research. Firstly, in the title Cath identifies the categories that are the major focus of her research study, namely, 'classrooms' and 'myths'. Secondly, she limits these categories by indicating the attributes that are of greatest interest to her, specifically, 'science' for classroom, and 'cultural' for myths. Further, the title indicates that methodologically she will be constructing evidence of myths in the science classroom by conducting a 'critical analysis' of classroom practices.

However, not only does the title indicate what the narrative is going to be like, it also positions the researcher in a theoretical sense. The theories that Cath presents, and around which she structures her research, represent her notions about how the world operates. Her personal theories are structured by her personal characteristics and life experiences, and influence the questions that she asks in her research and the assumptions that she makes about knowledge, values and reality (ie., epistemology, ethics and ontology). Use of the terms 'cultural', 'myths' and 'critical' indicate her research interest in specific public theories. This further helps to identify her theoretical position and the particular group of science educators from which she seeks legitimation. Table 1 highlights the importance of the title of Cath's study for indicating to readers some of the underlying theories which inform her study.

Table 1
Theories Implicit in the Thesis Title

Components of the Title	Implicit Theory
critical	critical theory
discursive practice	Foucault, power/knowledge
analysis	interpretive research
myths	semiotics, structuralism, post-structuralism
cultural	the importance of cultural factors to what happens in the classroom

Cath's thesis title signifies that her research study is informed by theories associated with post-structuralism and semiotics. Furthermore, the theoretical framework that is signified by the title indicates also the form of ethics which might be of significance to Cath in the conduct of her research. She believes that, because cultural factors constitute the focus of her research, the ethics that inform the research should also reflect an awareness of, and a concern for, cultural factors.

Research and Ethics

Ethics are related to the general purpose of research. In Cath's case, her research is based on the assumption that socio-cultural factors have a primary influence on learning and teacher practice in the science classroom. Therefore, the ethics that guide her research must be consistent with this assumption. For many researchers, the ethics that guide their research is based on their notions about knowledge (ie., the focus of their research questions) and on their basic beliefs about the importance of their research. Many reasons are proposed by researchers to explain why their research is important and worthwhile, and to describe the relationship between research and the generation of new knowledge.

Sometimes, researchers might claim that all knowledge is intrinsically good and so the methods that researchers use to gain knowledge is unimportant. Such an argument was used by researchers to claim that present-day scientists should be able to use the data on hypothermia collected by Japanese scientists who experimented on prisoners-of-war during the Second World War, the argument being that the knowledge is worthwhile even though the manner of its generation is considered to be unethical. This type of ethics is called *teleological ethics* and its organising characteristic is the notion that knowledge is value-free.

Other forms of research ethics emerged as researchers examined the relationship between reasons for conducting research and research methods considered to be appropriate. Another example of research ethics is described by the relationship between research that will generate knowledge designed to help individuals, and the belief that such research should be based on an acceptance of universal moral laws such as informed consent. This form of ethical approach is called *deontological ethics*. Examples of research ethics and their relationship to the rationale for conducting research are shown in Table 2.

Table 2
Relationships Between Reasons for Conducting Research, Research Ethics and Their Organising Characteristics

Reasons for Conducting Research	Research Ethics (after Brickhouse, 1993; Flinders, 1992; May, 1980)	Organising Characteristic of Research Ethics
Because knowledge is intrinsically good	Teleological	Knowledge is value-free
Because knowledge is useful	Utilitarian	For the harm/good of society
Because knowledge will help individuals	Deontological	Universal moral laws exist
For a better society	Advocacy/ Emancipatory	To empower minorities
For fidelity/care	Covenental/ Relational	Caring relationships are of primary importance
For socio-cultural awareness	Ecological	All relationships and individuals exist in webs of culture

The theoretical framework that Cath is evolving is consistent with the *ecological ethics* of David Flinders (1992) who argues that research should examine the classroom as a community and habitat. Within this ethical approach, analysis of metaphors is important, particularly 'dead' metaphors which "generate taken-for-granted patterns of cultural understanding" (p. 109) that we call 'cultural myths'. Ecological ethics aims for cultural awareness in the generation of knowledge from research. This includes an explicit awareness of the nature and role of language, especially the style of expression used throughout the research. This ethical approach emphasises the aspects of research that Cath thinks are important and constitutes an ethical framework for her research. Because she believes that the ethical, theoretical, political, epistemological and methodological frameworks of the study are inter-related, the literature synthesis of the study is an examination of the siting of her research in the cultural web of science education research.

The Politics and Ethics of Theory and Literature

Some interpretive researchers believe that researchers either should have no theoretical framework or should suppress their personal frameworks before they start generating data. They argue that early recognition of a theoretical framework might restrict the range of data that they generate. However, do researchers who say that, "I don't read anything before I go into the field. I want to keep my mind open" really mean that "I don't want to read about the area of research I'm involved in, I might have to reassess my personal theories before I get into the field," or "I don't want anything to get in the way of my theories"?

It seems to be a naive approach to positing the relationship between empirical research and theory to assume that the researcher's mind, unfettered by theoretical notions, can be the perfect conduit for collecting theoretically-unpolluted data from an experimental situation. It reminds us of the 'philosopher's stone' of 'inductive-empiricism' which advocates theory-free observation. It seems to us that, if researchers do not read widely of previous research reports related to their area of research interest, then they have not read about a range of theoretical possibilities and, consequently, their idiosyncratic theories are likely to have an inordinate influence on their observations and data generation. According to ethnographer Martin Hammersley (1992), "we neglect theory at our peril" (p. 34).

According to Merriam (1988), in relation to a research study our theoretical lenses influence the nature of the research questions, research design, how data are generated, the role of the researcher, and the analysis and interpretation of the data. We believe that the development of a theoretical framework allows the researcher to develop a coherent theory of their own. Importantly, it assists the researcher to reflect critically on their extant personal theories and cultural myths. Reading widely can make the researcher aware of other theoretical options. Cath believes that this stage of theoretical development is essential if she is to make sense, in an insightful way, of what happens in science classrooms that she visits.

Theory and the Use of Language

As we mentioned previously in this paper, the language used in research reports is recognised by the members of a specific research group, such as science education, and has meaning for the members of that group. However, often the language used to express ideas in science education research is unexamined. When we write in a particular way or use particular grammar and syntax we are signifying to our audience that we hope to belong to a particular research 'camp'. For example, if we write about 'sample' or 'participants', 'data' or 'texts', and 'learning environment' or 'classroom', we identify ourselves as belonging to one or other of particular (and sometimes competing) theoretical enclaves. Although our choice of language depends on our theoretical perspective, the choice also is ethical and political.

The style that we select to use in our presentations of our research (including this paper) is important because it indicates our theoretical orientation. As we conduct a literature synthesis, we interpret reports from other researchers about a particular aspect of research that provides background for our own study. When we present these interpretations in writing, we write to make our interpretations convincing. Consider the following contrasting language styles of extracts taken from a research report by Hackling and Garnett (1991) and from Cath's thesis. Both present interpretations of a report by Woolnough and Allsop (1985) on the purposes of practical activities in the science classroom.

> Woolnough and Allsop (1985) have identified three aims that can be validly achieved through laboratory work: the development of process skills and laboratory techniques; getting a feel for the phenomena; and being a problem-solving scientist.
>
> (Hackling & Garnett, 1991, p.1)

> The emergence of matters-of-fact through observation of nature in the practical activity and the eminence of the experimental report have led to the mythification of the practical activity in the school science classroom. Practical activities are also designed to introduce students to the craft of science where they learn to use equipment appropriately and to the culture of science through investigations that apparently mimic the work of scientists (Woolnough & Allsop, 1985).
>
> (Milne, 1994 in preparation)

Clearly, both groups of researchers used the paper by Woolnough and Allsop for the purpose of illustrating or supporting a particular notion about the role of practical work in the school science classroom. However, their underlying theoretical perspectives are very different, and this difference leads to the use in each case of a different form of prose. Hackling and Garnett use apparently non-emotive language to distance themselves from their interpretations of the Woolnough and Allsop paper. Their prose seems to imply that they are factually reporting on the data from the paper and that anyone else who reads that paper would make the same interpretations that they have made about this paper. By contrast, Cath wants to convince readers that they should share her concern about the need to be aware of the temptation of identifying practical activity as equivalent to science education, a process in which a metonym (in which a part is equated with a whole) becomes a myth in which the part *is* the whole.

Cath uses emotive language to encourage her readers to think about practical activities in a different way. In this case, her theoretical underpinnings are that myths are important, that as educators we need to be aware of them, that it is possible to use socio-linguistic theory to construct evidence of myths in classroom practice, and that there is the possibility that there exists myths associated with the use of matters of fact, practical activities, experimental reports and scientific language in the science classroom. Her approach is rhetorical to the extent that she attempts to persuade her readers that her claims have merit (Melia, 1992).

Conclusion

In this paper, we have discussed briefly the role of theory, legitimation and values in interpretive research. We have argued that researchers' personal premises about these key organising components influence the methodology of their research and the literary form used to report it. We believe that it is important for interpretive researchers to address these issues when they are planning, conducting and reporting their research. In order to be critically self-reflective researchers need to consider their perspectives not just with regard to theory, research questions and methodology but also in relation to the ethics that inform their research and the politics of their narrative.

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COGNITIVELY DIFFERENT? AN EXAMINATION OF THE THINKING LEVELS OF SCHOOL STUDENTS, TRAINEE TEACHERS AND PRACTISING TEACHERS IN WESTERN AUSTRALIA

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Introduction

Much concern has been expressed about the ability and willingness of primary teachers to teach science in their classrooms with any level of competence. Standards were found to be so low in the Speedy study that "the panel considered recommending abandoning science as part of primary education" (Speedy et al., 1990, p.82). Without the required science content base (and an accompanying capacity for good thinking) Tobin and Fraser (1990) comment that teachers will be "unable to focus student thinking, unable to provide appropriate feedback, unable to discuss effectively the content dealt with in different classroom environments".

The data presented in this paper are part of a much larger research project which looks at two main areas of cognition for primary teacher trainees: their understanding of basic science concepts and their cognitive levels of thinking. The rationale for this study was that without teachers who have subject mastery, levels of cognition and dispositions which are significantly superior to the students that they teach it will be impossible for the classroom teaching of science to reach an acceptable, let alone exemplary standard in Western Australia. The implementation of Outcome Statements in our schools will require that conceptual understanding of science be developed and that teachers, themselves, are able to model the critical thinking behaviours required to construct meaning and to evaluate experiments. The data presented have been gathered over several years on 3 main cohorts: Year 7 Western Australian school children (N = 1100), 2nd year Curtin teacher trainees (N = 100) and 2nd year Edith Cowan University (ECU) teacher trainees (N = 100). Data from other similar research have also been included for comparison purposes. The research question posed here was "Are primary teacher trainees cognitively different to the children that they teach?"

Subject Mastery

Concept mastery

Several questions taken directly from the Year 6 Western Australian science syllabus (Education Department of Western Australia, 1983) were used to assess concept mastery by the cohorts. By way of examples, one question asked how the apparent movement of the sun around the Earth was responsible for different time zones; another asked why a car needed petrol; and another required students to draw a simple working electrical circuit to include a battery, wires and a lamp.

Interestingly, responses to the first question showed that 14% of the teacher trainee cohort believed that the sun actually did rotate around the Earth, which was a figure not much different to that of the Year 7 cohort, where 15.5% held the same belief. With the electrical question, it was found that 18% used no wires in their drawing, 10% used only one wire, 39% used the wires incorrectly, and only 19% were able to draw the correct working circuit. Only 1.3% of the teacher trainees could actually draw this elementary circuit and also indicate the flow of current around the wires correctly!

Misconceptions

Biological questions taken from Osborne and Freyberg's (1985) research were used to probe common misconceptions held by the university student cohort. Questions related to whether given objects were thought to be living (see Table 1) or were animals (see Table 2).

Table 1
Percentage Who Believe Object Is Living

Object	Osborne		Grant		Pears & Skinner	
	Y7	Y12	Y10	Y12	Curtin	ECU
Person	100	100	100	100	92	100
Fire	40	5	44	20	16	28
Car	15	2	23	7	5	2

Table 2
Percentage Who Believe Object Is An Animal

Object	Osborne			Pears & Skinner	
	Y7	Prim T/T	Uni Biol	Curtin Y2	ECU Y2
Cow	98	100	100	100	100
Person	57	94	100	92	95
Worm	37	77	99	81	64
Spider	22	65	97	78	61

Tables 1 and 2 give a comparison of the original Osborne and Freyberg data with this project's teacher trainee data as well as presenting some recent data derived from TAFE students (Grant, 1994). It is noticeable that the level of misconceptions for the teacher trainees is similar to that of the school children and TAFE students.

Levels of Cognition

Piagetian levels

In the UK, Shayer and Adey (1981) developed Piagetian-type tests to identify the levels of cognitive development for British school children. The same Science Reasoning Tasks (SRTs) used by Shayer and Adey were used to place Western Australian teacher trainees on the Piagetian developmental continuum and to allow comparisons with the British norms to be made.

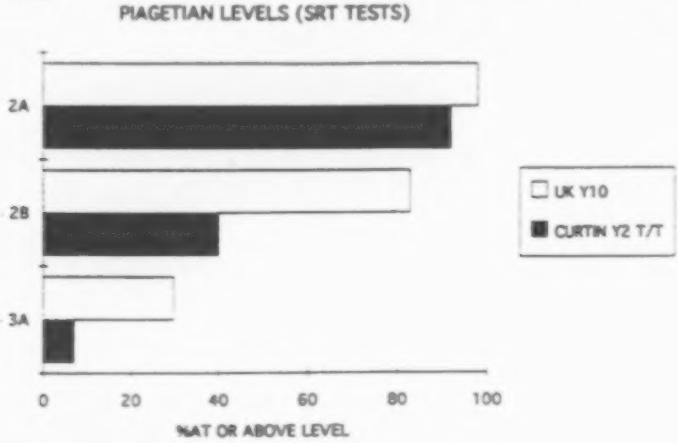

Figure 1 Comparison of teacher trainees (T/T) with UK Year 10 norms

Figure 1 shows that, whereas about 30% of the British average Year 10 students have reached the 3A (Early Formal) stage, only 7% of the Western Australian teacher trainee cohort were found to have reached the 3A level, using the SRT measure.

SOLO data

By way of triangulation, the SOLO Taxonomy levels (Biggs & Collis, 1981) were also used to analyse the university students' responses to the questions in science taken from the Year 6 Western Australian syllabus. Responses were coded according to the taxonomy as:

Prestructural - no relevant bits of information given;
Unistructural - one bit of relevant information given;
Multistructural - several bits of relevant information given;
Relational - most bits of relevant information given, with links;
Extended abstract - relevant information related in an open-ended fashion.

Table 3
Equivalence of SOLO and Piagetian (SRT) levels

Score	SOLO	Piaget	
0	Pre-structural	1	Pre-operational
1	Unistructural	2A	Early concrete
2	Multistructural	2B	Late concrete
3	Relational	3A	Early formal operational
4	Extended abstract	3B	Late formal operational

Table 3 shows the SOLO taxonomic scores used in this research and the Shayer and Adey cognitive levels which are deemed to be equated to them. Results of a recent DEET (1994) survey of Year 7 students which used similar questions and methodology are shown in Table 4 alongside data for the teacher trainee cohorts.

Table 4
Percentage Of Students at each SOLO Level (Rounded)

Level	Curtin (n=40)	ECU (n=86)	DEET (n=1136 Y7)
1 / Ps	23	24	43
2a / Us	52	51	41
2b / Ms	23	15	12
			3 (Pr)
3a / Rel	2	10	1
3b / Ea	0	0	0

Table 4 provides further evidence, on a different measure, that only a small fraction of the teacher trainees (2 - 10%) are at the stage of Early Formal reasoning. This percentage is not too dissimilar to that of the Year 7 students reported in the DEET study, but note that the DEET analysis differentiates the Multistructural level into two sub levels.

Reasoning skills

The New Jersey Test of Reasoning Skills (NJTRS, Shipman, 1982)) has been widely used for international comparisons of cognitive thinking levels. The NJTRS includes the testing of: induction, deduction, ordering and sorting, inferring, and analogical reasoning skills.

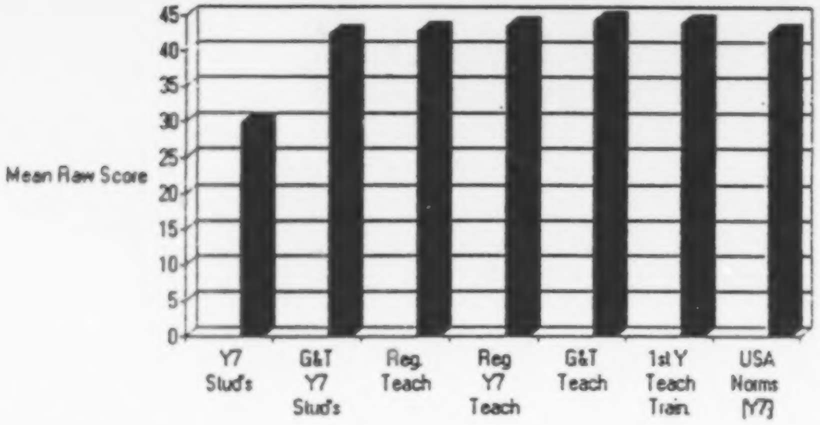

Figure 2. New Jersey Test of Reasoning Skills scores for different cohorts

Figure 2 reveals that there are no significant differences between Western Australian first year teacher trainees, current practising Western Australian primary teachers and average Year 7 USA students. Based on these norms, Australian Year 7 Western Australian students were found to have reached about the same level of reasoning abilities as Year 4 students in USA.

Discussion

There appears to be little difference between the levels of conceptual understanding of primary teacher trainees in Western Australian universities and the students which they are likely to teach. Indeed, many teacher trainees hold the same misconceptions typical of a child's view of the world around them (eg. "The sun rotates around the Earth"). In the area of *Energy and Change* less than 20% of the teacher trainees were able to draw a working electrical circuit of the most elementary kind.

Comparisons between the cognitive developmental levels in the UK and these Western Australian data place the Teacher trainee cohort below the Year 7 British norms. The SOLO data serves to reinforce these findings on Piaget levels and makes the ability of our future primary teachers to understand and teach the content and concepts of basic, elementary science highly problematic. The overall level of reasoning abilities reveal major deficits in the essential skills of critical thinking and analysis – essential cornerstones to the scientific enterprise.

Implications

1. The misconceptions held by teacher trainees and practising teachers in Western Australian are likely to continue unless these are identified and corrected in some way. The extent of this problem was revealed in the recent DEET (1994) study where entire classes of Year 7 students were found to have misconceptions perpetuated by their teacher.
2. Teacher training courses in Western Australian need to adopt a constructivist teaching and learning model. In addition, direct instruction for cognitive acceleration (for example, see Adey, 1988) needs to be implemented in order to enable future teachers to deal with the higher order outcomes demanded by the National Outcome Statements for science (MSE, 1994).
3. Current assessment models prevalent in the primary and secondary schools of Western Australia need to reflect the development of higher order cognition and *deep* approaches to learning. Much current practice involves the following of prescribed

routines and the reproduction, rather than the generation, of knowledge. Improvements can only come via better cognition (critical, creative and inquiry thinking). Crucial to the enterprise is the distinct need for the quality, rather than quantity of learning to be rewarded through the examination system.

4. The most potent influence on the adoption of *deep* versus *surface* approaches to learning is that of dispositions within the classroom. Teacher trainees must be encouraged to develop beliefs, values and attitudes which nurture good thinking and a constructivist methodology. Central to this is the notion of classroom environments which encourage and develop these. The importance of modelling such exemplary classroom environments within teacher training programs themselves becomes obvious:

> At the heart of the constructivist/ metacognitive messages for teacher education is the need for student teachers to be helped to recognise their existing ideas and belief s (in science content and in learning/teaching roles), to have an informed basis for personally evaluating the appropriateness of these of these ideas and beliefs, and so then to be able to decide whether or not to embrace new conceptions and consequently reconstruct old.
>
> (Gunstone & Northfield, 1992)

Summary

This research has indicated a cognitive crisis in our educational system at all levels, with the implication that current Western Australian primary teachers do not possess the required levels of cognition nor the conceptual grasp of science content to teach science with any degree of competence. It can be seen that on most measures of cognition there is little difference between the abilities of future teachers and the primary students they will be teaching . There is an urgent need for the upgrading of teacher training courses, professional development of teachers and an overall strategy to enhance thinking skills.

Prologue

As far back as 1975 the levels and quality of cognitive development of Australian school students were found to be lower than expected (Connell et al., 1975). In fact, Connell argues that "Many adolescents would have difficulties with reasoning and decision making in science, social science and literary material" (pp. 129). Clearly this view supports the findings of this research on the Year 7 cognitive levels and those of those adolescents currently in teacher training institutions.

The recently released profiles of student achievement in Western Australian government schools (science) attempt to assess current levels of concept acquisition using similar measures and methodologies to those described in this paper (MSE, 1994). At its most liberal interpretation the MSE results support the findings in this study in that the majority of Year 7 and Year 10 students can only demonstrate a Level 2 understanding. In the case of the Year 10s in particular, the measured outcome was way below what was expected by professional educators. In the case of the *Earth and Beyond* strand a typical Year 7 and 10 response was prefaced on the misconception that the sun rotates around the Earth. Interestingly, the example given for a Level 3 response (MSE, 1994 p. 56) actually displays the same misconception!

This research has highlighted the small current differences in conceptual understanding and quality of cognition between cohorts of widely different ages. The same pattern emerges from the MSE's own data when the science abilities of Year 3, Year 7 and Year 10 are compared.

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PAYING THE PRICE FOR SUCCESS IN SCIENCE

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Sue	*Like we all did this test and we all practically failed it, there was hardly anyone who passed.*
Nadia	*But some people got it all right. Like the squares!*

Sue and Nadia are upper ability Year 10 students at Spencer Senior High School talking about their first test in the topic Mining, Chemistry and Industry. Although they did much better on the next test, they don't like chemistry much, and don't think of themselves as successful science students. Sue is taking no science next year, Nadia is taking Human Biology, and their friend Ellen has chosen Human Biology and Physics.

My discussion with Sue, Nadia and Ellen was about a number of things, but of interest here are their perceptions about what it means to be a successful student in science. This is one aspect considered in a larger study about girls' and boys' reactions to life in schools.[1] This paper is a preliminary attempt to assemble some of the ideas students and teachers have about success and the gendered way in which they construct and deal with it. The data presented here are drawn from discussions with 46 teachers and 62 students in three Western Australian schools, whose pseudonyms are Clark, Middletown and Spencer Senior High Schools. The paper considers three aspects: students' perceptions of success, teachers' perceptions of success, and action taken in schools to address issues perceived to be related to success.

Students' Perceptions about Success in Science

Invariably, when asked about success, students associate it with high academic grades, hard work and a price to pay. Sue made this clear:

Interviewer	*What would it take to be a successful student in the school?*
Sue	*You'd have to really knuckle down to homework. I'd hate to be a person who just does their homework all the time and have no social life. Because you're happy at school but no one would talk to you because you wouldn't socialise.*

In the same school, I talked with three able Year 9 boys.

Interviewer	*What are the things that go towards making a successful student?*
Michael	*Aim for the top. That's what I reckon. Aim for the top and if you don't get it well at least you've tried.*
Jason	*Just keep trying*
Adam	*And if you've aimed for the top, you've got the top grades*
Jason	*Keep up there with it*
Michael	*Yes but if you've aimed for what you want and you don't get it, you can go back and do other things that you like. Like have other interests as well.*
Jason	*Even if you don't go right to the top.*
Adam	*Some education is better than none.*
Michael	*Put all your effort into what you're going at. Not say "Oh I'm not very good because I'm not at the top" and fall back.*
Interviewer	*Mmmmm. Do you think there are other things besides academic grades that make for success?*
Michael	*Well if you're stuck behind a desk doing your work just to get good grades, you're going to become boring so no one will like you anyway. So you've got to*

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[1] This study is part of an ARC-funded project led by Sue Willis and Jane Kenway. The idea for this paper came from discussions with Sue, Jane, Jill Blackmore and Maggie Woodhead.

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	have friends, a social life as well. You've got to combine that in so you're still doing the work but you get a good life.
Interviewer	*Do you think it is hard to combine the social life?*
Jason	*Very hard.*
Interviewer	*What makes it hard?*
Jason	*If you do your homework you're called a square, but if you go to the party it's alright but you miss out on your grades at the end.*

In general, students' ideas were consistent. It was hard to get them to nominate anything other than grades as being the most important aspect of success. But there was a trade-off: homework for social life. Was it a problem being a called a square? Sue and her friends explained:

Nadia	*You get called a square but it doesn't really mean much. They say "Oh. You're a square!" You just sort of laugh at them. The only ones who really get it are the people who don't talk to you, they just do their work. You ask them something and they tell you to get lost, 'cause they don't want to tell you or help you.*
Interviewer	*So it's not really that they get high grades...*
Nadia	*They usually do.*
Interviewer	*They get called squares if they just keep to themselves and don't share?*
Nadia	*If they don't help anyone.*
Sue	*They don't socialise, they stay away from everyone else, they're like a different group by themselves.*
Ellen	*And like you try and socialise with them and be nice and they say something and then just kind of go all quiet again and don't say a thing.*
Interviewer	*And do they have any friends?*
Ellen	*Yes, there's a whole bunch of them.*
Nadia	*Yeah. A square group of males and a square group of females.*
Interviewer	*Oh? So they don't mix?*
Nadia	*That's another thing, they don't talk to girls.*
Ellen	*If you go up to a square guy they say "Oh shut up", and he'll go all flustered. Like Craig.... if you go up to him and talk to him, he'll go (assumes postures and gestures to indicate embarrassment on part of boy): "Oh how embarrassing!"*

It seems that students link grades with success in science, but good grades need hard work and a loss of social life. Students willing to aim for success were presented with a dilemma. Sacrificing their social life to do well academically resulted in teasing, like being called a square. Some students could take this as a joke, but for those students whose interests are primarily academic, or who are less skilled socially, the teasing is more serious. They are the "ones who really get it", a situation hardly conducive to improving their social skills.

Teachers' Perceptions about Success in Science

When science teachers at Middletown Senior High School were asked how they defined success for students, they offered broader views:

Terry	*For me, it's going into a class and feeling comfortable in that class. If you can go into a class and feel comfortable and know that the students are basically "on task" then I will call them successful students or that class a successful class. Whereas in other classes that you go into you're struggling and you're basically keeping control rather than teaching. I'd call that class and most of the students in it, less successful.*
Aileen	*And that's also related to the enjoyment students are getting out of activities they're doing. I think that there has to be some element of enjoyment on the students' behalf.*

Terry	*The extent to which they contribute, join in. They're unresponsive, but they might achieve well. At that level you'd say they were successful, but as a teacher, I wouldn't call it successful because they're not joining in.*
Interviewer	*The kids themselves, how do you think they define success among themselves?*
Terry	*Whether they get A's or B's. That's the obvious way, in terms of achievement. ... When it comes down to it, most students define success as 50%, 60%, or better, and ...*
Aileen	*I don't think that! If I look at my Year 9 group, I don't think that those students would know what the word success meant. I don't think it is part of their vocabulary and I'm being honest about that. But when you're looking at your better students then there's no doubt that they equate success with the absolute grades they get.*

Raylene, a Deputy Principal at Spencer Senior High School, offered her perceptions of a successful student:

Raylene	*I think that it is one that is enjoying learning and is achieving to the best of their ability. They'd be the two things I would put in there.*
Interviewer	*And do you think students themselves perceive success in a similar way?*
Raylene	*It concerns me a bit that some of them seem to draw back from success and I think perhaps they don't know what success is? They think that success is probably an A on a report. But a lot of them are even a bit afraid to aspire for that, one, because it's probably unattainable for some of them, but others because of other things which are associated. They associate certain other qualities with success academically, the kids do, and they're often not favourably received socially.*

There are different perspectives here. From the teachers' point of view, success is more than grades, it is participative, successful students enjoy their science and "join in". Teachers hope that all students achieve "to their best of their ability", but they recognise that success in science is not possible for every student. When they can achieve, teachers believe that students use grades as their criterion. But teachers also recognise that success can have adverse social implications. Terry and Aileen gave their perceptions:

Interviewer	*We were talking to some Year 9's yesterday who were in the top class and described themselves as squares. Is that an issue?*
Terry	*It's become a term, absolutely!*
Aileen	*You're not a popular kid.*
Terry	*Boys and girls both.*
Aileen	*Definitely. It's not the done thing to show academic excellence.*
Terry	*Success academically means you're a square socially and whatever, you're a failure.*
Interviewer	*Is it possible to be successful both at grades and socially?*
Aileen	*You get the exceptional kids like that, but there are not many.*
Interviewer	*If you've got kids in your class who are in danger of being called squares, are they able to cope with that? or do they try to do not so well? I'm just wondering what the really able kids do.*
Aileen	*The really able ones have that degree of maturity they're able to cope with that, sure.*
Terry	*They rise above it. A lot depends on what they get at home. I've seen able kids go the other way, start to draw back, start becoming disruptive, try to be a rebel. Remember that girl who pulled out, basically? Aileen's just had an interview with a parent of a girl who's extremely bright but has pulled back and started to misbehave.*
Aileen	*I don't think there is any hard and fast rule.*

Teachers' perceptions are congruent with those of students': getting high grades frequently means getting teased, and coping with teasing can be difficult. Withdrawal socially and academically can be outcomes. Teachers become concerned when they perceive students to be drifting along, perhaps not doing their best, and try to encourage them to continue in science. Graham, who was Sue's, Nadia's and Ellen's science teacher at Spencer Senior High School, spoke about a Year 10 boy's subject choice:

> *He is a very, very smart boy. He is good in class. He is well-behaved but he is just slack and he wasn't going to do chemistry and I said "That's a pity because you would do well". Then he said "Oh I am taking chemistry now" because he couldn't get something else because of the grid line [timetable], so I said "I suspect you'll do really well." The guy just said "Oh, I am going to work [study] next year."*

Graham also referred to a girl in Sue's class:

> *she's pretty bright, but she's not going to do chemistry. She is going to do journalism and it doesn't fit in her pathway. I spoke to her and said that it was a pity and she just said "I'm not going to try. I am not going to push it. I don't want to sort of get left." The emphasis is with the pathway system [of subject choice]. Those sort of kids, it's a shame they miss science.*

Graham's reporting of these two incidents flags an issue which relates to students' confidence in science. Being forced to take chemistry by accident, as it were, was no problem for the boy, he would change his present behaviour and study. For the girl, however, taking chemistry was not something she was willing to try. Girls' apparent reluctance to do science received much comment and their subject choices were often perceived to be a problem. A counsellor at Clark Senior High School reflected:

> *When the Unit Curriculum was introduced, there was a problem with girls' choosing the less academic units, eg. not doing the more advanced science units which led on to physics and chemistry. ... More recently, the school has set up courses that are positively trying to encourage girls to do the more rigorous subjects, like the Year 11 single-sex science class, which hopes to encourage more girls into physics and chemistry.*

Teachers' perceptions about success, particularly for students perceived as able, raise two issues. First, teachers want students to do their best in the subject they are in, so if they seem to "draw back from success", it is cause for concern. Second, teachers hope students will do the most academic and hardest subjects of which they are capable. These perceptions implicitly link success with specific subjects. The success of students performing to the best of their ability is qualified according to whether they are doing the "right" subjects, and for those perceived to be able, both male and female, the "right" science subjects are physics and chemistry. These kinds of perceptions underlie the kinds of actions schools take to support their students and encourage their success.

School-Based Efforts to Help Students to Success

Each of the three schools offered some kind of program to support students perceived to be at risk academically. In this section, two kinds of program are described. One is a 'Fast Track' program for able students which became known as "The Squares' Convention", and the other is the implementation of single-sex classes. In the final section, some unintended consequences of linking success to performance in science and mathematics are explored.

"The Squares' Convention"

At Spencer Senior High School, a group of able Year 9 students were targeted for a motivational program. They were perceived by teachers to be under-achieving, receiving B's when teachers thought perhaps they were capable of A's. The 'Fast Track' program was supported by a small grant from the District Education Office. Approximately the top 20%

(around 30) of the Year 9 students were selected for a series of breakfasts and a workshop at the District Office. Most activities were aimed at enhancing self-esteem, and to give students skills to cope with negative outcomes relating to achieving at a high level. The Deputy Principal reported:

Raylene	*Last Wednesday the group went down to the District Office. Comment was "It's the square convention today"!*
Interviewer	*So when you say "square", you mean unpopular socially?*
Raylene	*The kids came up with the "Square Convention". One of the teachers came up and said it was a real shame, but it was good because it came out and was discussed openly, but the kids were seen as not the really popular ones. The girls that are popular in Year 9 unfortunately are not the ones that are the top of the achieving terribly much of the time. I think that's a really hard time for them because they are torn between achievement and getting on with it and going somewhere or being ever so popular socially. So yes, I do think there's a big pressure on them to appear to be a bit flighty and not to be terribly clever.*
Interviewer	*And do you think that the boys have a fear of success to some extent too?*
Raylene	*I do think it's just as much on them, yes. It's purely personal [opinion]. If you asked them, I think they'd see successful as being popular with your peers, fairly able, sporting OK. You can function OK. But I certainly don't think they put academic achievement as being the highest on the list, it would be other social attributes that would come higher.*

Michael, Jason and Adam, who, as quoted earlier, wanted to "aim for the top", were involved in this program. How did some other students react?

Interviewer	*Can you tell me a little bit about the Squares' Convention? Who gave it that name, do you know?*
Jenny	*Jane did.*
Jane	*Me! (laughter) That was just as a joke.*
Interviewer	*Is that a pretty good name for it then?*
Jane	*Umm. (sigh) I don't know.*
Jenny	*Yep! (laughter)*
Interviewer	*What was the purpose of that [program], do you know?*
Jenny	*Bonding*
Jane	*No, I think it was, um, not to let us slip back down in grades and to keep them up.*
Renee	*To keep encouraging us to work harder.*
Interviewer	*OK. And why do you think the teachers thought that you might need encouragement?*
Jane	*Um, because, I think, you know, that if you get good grades people call you squares.*
Renee	*Yeah*
Jenny	*Yeah, it's like, like friends and other people that pressure you if you do well.*
Interviewer	*Who would call you squares if you got good grades?*
Renee	*The people who don't get good grades!*
Jenny	*Yeah.*
Interviewer	*Would they tend to be boys or girls?*
Jenny, Jane	*Both*
Interviewer	*And is that actually quite a serious put-down to be called a square?*
Jenny	*(sigh) Umm*
Renee	*Yeah*
Jane	*Oh, some people might take it seriously.*
Renee	*You just laugh it off.*
Jane	*Yes. You see that is why we went, so they could tell us how to deal with it. That is one of the things that we did.*

Interviewer *So, actually how to handle being quite clever?*
Jane *Yes. And you know, the pressure.*

And did it help?

Interviewer *Can you remember how you came away from that? How you felt about yourselves?*
Jenny *Yeah*
Interviewer *Can you tell me Jenny?*
Jenny *Um, I felt more confident.*
Jane, Renee *Yes*
Jenny *I didn't worry as much about what other people said.*
Interviewer *Right. And do you find that you have been able to maintain that, or not?*
Jenny *Yeah. We still meet most weeks*
Renee *Every Wednesday, yeah.*
Jane *I reckon that was good because it was before the social [school dance].*
Jenny *Yeah*
Jane *Yeah and I felt really good about myself.*
Jenny *Yeah, before the social and that.*
Jane *Yeah we had a disco and a social that night, so you felt a lot more sure about yourself.*

The mathematics teacher of the Year 9 students involved in the Fast Track program reported that the students were more supportive of each other, and more willing to achieve. She said that "kids can now admit publicly to being successful", and she thought the work ethic had improved in the class. This program was judged both by teachers and students to be successful. It is significant that the girls reported feeling more confident on the social occasions, gaining more than academic confidence.

Single-Sex Classes

Students in the Fast Track program were offered support because it was feared that they would underachieve and drift into less "academic" units. Although students and teachers agree that both girls and boys are teased when they are successful, it is the girls rather than the boys who are considered more likely to drop out of science and they are often targetted for support. This seems to be a direct result of linking academic success, particularly in upper school, to performance in science and mathematics.

Some schools in most Australian states have introduced single-sex classes in an attempt to encourage the participation of girls in science (and mathematics). All three of the schools mentioned here have, at one time, tried single-sex classes. The Year 11 single-sex girls' class referred to by the counsellor at Clark Senior High School was perceived to be very successful for the girls in it. One science teacher reported:

> *I think it was a bonus for the girls. They've grown in so many ways. Each one has become a leader in her own field, the ones that didn't become strong academically, have socially developed as leaders – even if it's organising windcheaters and getting all the names on them – she wasn't particularly strong on the sciences but she's been seen as a leader in that way.*

Middletown and Spencer Senior High Schools introduced single-sex classes in Years 8 and 10 respectively, and Spencer has continued with some single-sex classes. Frequently, and especially at Year 8 level, before students' subject choices become clear, teachers find it difficult to judge whether or not the classes are effective. Aileen and James talked about their single-sex classes at Middletown:

Aileen *It's very difficult because we've got no yardstick to compare with, but certainly if I reflect on [mixed] Year 8 classes that I've had before, I do have an extremely wide ability range. I've got girls right up there who are getting* *virtually full marks for their test and girls who have got reading problems. I seem to have got a greater number of girls who are more animated and prepared to participate and show definite leadership skills than have been evident when I've taken the mixed-sex classes, but it's a different group, so it's very difficult to be sure whether it's due to group dynamics, or the fact that they've been taught in that situation, or whether I'm just more aware because I've been teaching them as a single-sex group.*

Interviewer *What about your boys' class, James?*

James *I don't find much of a difference in their behaviour or their attitudes. So I don't think that anyone has really benefitted by having an all boys' class, though some kids do say that, like, we don't feel that if we answer wrong, the girls will laugh at us and that sort of stuff. So a couple, I think, are more free and are ready to answer. But in general, I don't think there is much of a difference.*

Interviewer *Is it harder in the single-sex or the mixed-sex classes for the able kids? Is it harder for girls to be successful in front of boys or harder for boys to be successful in front of girls?*

Aileen *With my Year 8 [girls'] class, and again it's very difficult to judge, there is a healthy competition. They take pride in beating the next one, even if it's by one or two marks. I haven't seen evidence of that to the same extent in the mixed class. It doesn't happen in my Year 9 [mixed class] but I'm just reflecting back on classes that I've had in the past.*

James *I think the boys are a litle more reluctant to be called squares. They would rather fit into the general thing as compared to girls. So I have noticed a couple of my boys who, you know, they tend to just hold back a bit, because they are considered squares in the class.*

Although generally perceived to have had some measure of success for girls, overall the advantages and disadvantages of single-sex classes are complex, as a separate project monitoring the Education Department's Single-Sex Pilot Project reveals (Rennie & Parker, 1993). Recently, this project has produced some evidence about teasing and success. Over 100 Year 9 students at Middletown responded in terms of their experience in single-sex classes in Year 8 and their current mixed-sex classes, as shown in Figure 1.

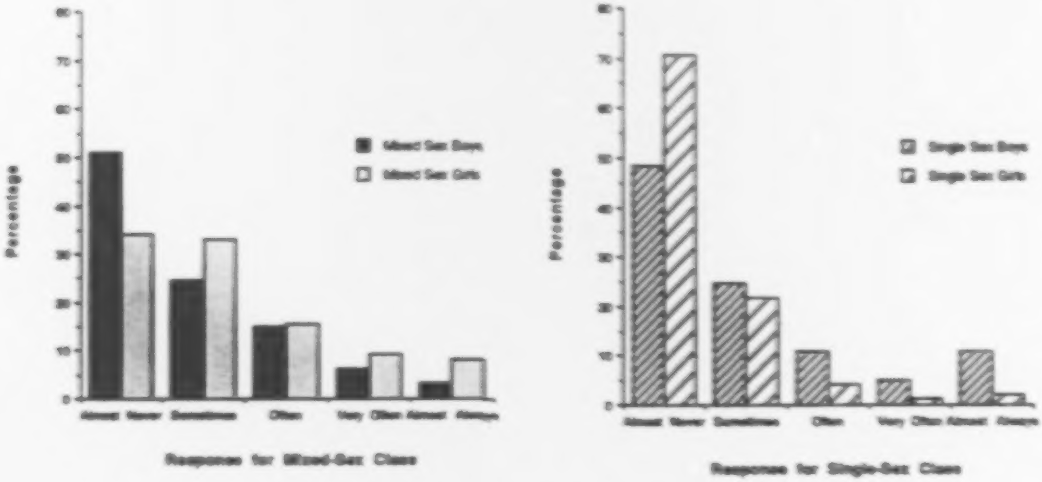

Figure 1. Students' Responses to the Statement "I get teased if I get good marks"

It can be seen that the patterns of harassment do have a gendered aspect. Those students who are teased most are boys in single-sex classes and girls in mixed-sex classes; those students who are teased least are boys in mixed-sex classes and girls in single-sex classes. These results bear out what Aileen and James observed, and are consistent with findings in other schools in the Education Department's Single-Sex Pilot Project. In terms of this single variable, single-sex classes seem to have an advantage for girls. Interestingly, there was little association with grade. Evidently when the less able do experience success, they also get teased.

Unintended Consequences

As pointed out earlier, success for able students tends to be linked with the higher level science and mathematics. Both the Fast Track program and the single-sex class initiatives were premised in the belief that students should be encouraged to do their best in the most academic subjects of which they are capable. Science and mathematics are regarded highly in the workplace, by tertiary institutions and by parents as passports to better jobs. TEE subjects are accorded higher esteem than accredited subjects. Students and their parents know this, and there is an unfortunate consequence. Despite the teachers' best efforts to advise students to enrol in subjects compatible with their ability, there are often large enrolments of students in physics and chemistry who have unrealistic expectations of success. One science teacher at Clark Senior High School noted:

> *I am concerned that we have three physics classes scheduled for Year 11 next year and the smallest is 24 students. It's one of the hardest subjects and many won't be able to cope. Colin (a physics teacher) is depressed because half of his [current] class failed the final exam – not very rewarding for a teacher. Senior Science and Physical Science are offered, but don't run because there are not enough takers.*

This teacher believed that the Education Department's view was "Everyone deserves the chance to fail", and this was the reason given for allowing students to make choices perceived to be inappropriate. Many of these students considered that risking a fail in physics in the hope of a D, was a better option than gaining a higher grade in a less prestigious subject like Senior Science. Across the school, teachers were concerned about this issue. English teachers at Clark discussed students' choices:

Kay *Kids choose subjects for socially motivated reasons, I think. Like "I must do top level maths because they are the hardest subjects so if I'm in them – even if I don't pass them – I am better". "I want to be a doctor even though I'm failing every subject so I must do top maths." I don't think it's a gender thing, it's a goal-oriented thing – their perception of what is socially acceptable.*

Darlene *Just as the other way they don't want to do "vegie" maths or "vegie" English. It doesn't matter what sex they are, it's whether they perceive themselves as capable and intelligent or incapable and "vegie".*

These teachers did observe gender differences in the subjects students chose:

Kay *Boys are choosing subjects that they can see they can get more jobs with, more with maths and science than they can with social science. They say to me "Why do you teach English when you've done maths and science?" It's like obviously you've chosen second best if you could do the others. There is still that math/science push for them.*

There was a belief that more boys than girls made unwise subject choices, as one Deputy Principal at Clark made clear. Unhappy with students' choices, she thought that "they choose above their abilities, especially the boys. Some girls under-select, according to their abilities". This deputy, as did some other teachers, perceived girls to lack confidence to go on with science and mathematics. Recall how Graham described the different attitudes of the able boy and girl, both reluctant to do chemistry at Spencer Senior High School. Forced to take chemistry, the boy was confident, the girl unwilling to try. Most teachers considered that social pressures to take high level science and mathematics were greater for boys than girls. According to mathematics teachers at Spencer Senior High School:

Jo	*Girls make more informed subject choices [in Year 11]. If they don't continue with maths, it's because they've thought about it, whereas boys persevere, even if they fail, they risk-take. But we lose some good girls this way. They don't choose maths.*
Jennifer	*Boys are less mature, they do maths because it is expected of them.*
Jo	*Some girls choose one math and have looked at two maths. Girls drop maths if they are not successful, but boys keep on going.*
Jennifer	*Girls are more realistic about what they expect they can do after school. Boys suffer from delusions of grandeur – even if they fail, they keep doing it.*
Interviewer	*"Risk-taking" and "delusions of grandeur" – are these concepts equal over different subjects for boys and girls?*
Sean	*Girls take risks in things like drama, boys don't.*
Jo	*[talking about her Year 12 Calculus class] If girls are coping, they come and get help. Boys won't admit it and clam up.*
Interviewer	*Why don't the boys ask for help?*
Jo	*It's a maturity thing. I've tried to get the boys to come and ask for help.*
Jennifer	*It's cultural. It's expected that boys can cope and know what they're doing – it's so ingrained!*

The net result of gender-based social pressures was perceived by many teachers to be problematic – too many boys in physics and chemistry and too few girls. A partial answer was being sought by pushing the pathway system for students' upper school subject selection. Students could choose Senior Science rather than physics and chemistry because it was on their pathway. The success of this strategy remains to be seen.

A Final Word

The issue of success in science has many contradictions. When students work hard and succeed well, many suffer teasing from their class mates. Those less able to pay this price, tend to "draw back". Teachers respond in various ways, offering students support and encouragement to do well and continue in science. In upper school, the status of science has other consequences. Students may not want to draw attention to themselves as high achievers, but they also want to avoid being labelled as low achievers, by enrolling in less academic subjects like Senior Science. Thus many, predominantly boys, enrol themselves in physics and chemistry with little chance of success. In contrast, a lack of confidence or ambition, or both, are perceived by many teachers to prevent able girls from enrolling in physics and chemistry, and they were viewed by some as less successful.

There is another consequence of the high status in which physics and chemistry are held. Recall the assumption that English was "second best" in Kay's comments about the "science/maths push". Teachers tend not to recognise that attempts to encourage able, but apparently reluctant, girls to enrol in science and mathematics effectively devalues other subjects in which girls also do well and are traditionally interested. A development at Clark Senior High School, made this clear. A new subject stream was introduced into the school, enabling specialisation in a combination of design and fashion. According to the counsellor, this was considered to be "OK, because it won't stop girls from doing the more rigorous maths and science" as it was a specialised elective in the school. Interestingly, this course did not qualify for a seeding grant from the Education Department, whereas the single-sex science class initiative, encouraging girls into physics and chemistry, did. The former was refused because it did not focus on non-traditional choices for girls. The result of the Department's decision was to overtly devalue the girls' choice to be involved in Fashion and Design, the upper levels of which career structure, it is interesting to note, are also dominated by men.

Kenway and Willis (1993) captured much about teachers' and students' perceptions when they asked whose interests are served when success for girls is defined by programs which suggest that "to succeed in the public arena they should assume a certain sameness with boys in subjects and career choice. At the same time many girls are aware that their futures will most likely not be the same as boys" (p. 24). These ambiguities were rarely addressed in the three schools involved in this study, but they may help to explain why many girls stayed out of science. Doing physics or chemistry meant giving up another subject that you liked, and the price of success was too high to pay.

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WOULD YOU EAT A GENETICALLY ENGINEERED TOMATO? 'PUBLIC' PERCEPTIONS OF BIOTECHNOLOGY

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Public Understanding of Science and Technology

Much of the popular – and academic – discourse about public attitudes to science and technology and the need for more effective communication have assumed what Wynne (1991) has called a 'cognitive deficit' communication model. Lay people, in this model, lack knowledge and awareness, and this needs to be overcome by more effective forms of science communication, such as better school science courses, the use of television science, through science and technology centres, or through print media.

An alternative 'social constructivist' or 'interactive' approach to ordinary people's knowledge gives much greater emphasis to the often well developed, but informal experiences which people bring to public issues. An apparent ignorance about science and technology topics may mask a high degree of local knowledge, such as that identified in a series of case studies in the UK on farmers (post-Chernobyl) and radioactivity (Wynne, 1991), elderly citizens and home insulation (Layton, Jenkins, Macgill & Davey, 1993) and parents with children suffering from hypercholesterolemia (Wynne, 1991). There is accumulating evidence that adults actively transform 'expert' knowledge in ways which makes it useful for them (Layton, 1986; Lave, 1988). Candy (1989) contrasted the positivistic position that 'knowing' is a kind of 'copying or replicating' with a view that adults

> reconstrue their circumstances through the application of their personal world view. The behaviour of people is seen as purposive and intentional, and thus researchers need to enter into the understandings which actors have of their own situations (p. 111).

A number of researchers have developed this approach into a theoretical framework known as 'situated cognition' or 'everyday cognition'.

This project builds on a continuing research programme in the field of the *public understanding of science and technology*. Early work began in 1988 and 1989, with small scale attempts to document knowledge and perceptions of science and technology of a random sample of Western Australian adults, and the potential sources of information on science and technology topics (Schibeci, 1988; 1989). These early efforts provided useful, but limited information. In 1992, as part of a combined Murdoch University/CSIRO Division of Water Resources project, we began to probe adult understanding of water-related phenomena (Schibeci, Fetherstonhaugh & Griffin, 1993). In 1993, we conducted a pilot project which investigated human nutrition (Schibeci & Wong, 1993; Wong & Schibeci, 1994).

Our continuing programme was recognised with the award of a large Australian Research Council grant to investigate (in the period 1994-6) a different aspect of the public understanding of science and technology: public perceptions of biotechnology. This paper reports some preliminary results in this project.

Public Understanding of Biotechnology

Biotechnology: The science

Biotechnology is a broader term than either genetic engineering or gene technology, although they are often used interchangeably in common use. Bud (1991) argues that two main meanings are intended by biotechnology. One meaning originates from the long tradition of modifying the characteristics of some life-forms to enhance their usefulness to humans. Modern biotechnologies, in this view, have emerged through a long process of incremental change going back to the Babylonians (presumably making it more a technology than a science?) and do not represent a radical break with the 'past'. It is this view, with its connotations of conservatism and safety, that the biotechnology lobby (industry, scientists,

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government) would like to become the basis of public understanding of the risks of biotechnology.

The other view, presented by Yoxen (1983), among others, suggests that biotechnology is a radically new emergent field of science and technology; a view clearly evident in the work of many anti-biotechnology activists such as Rifkin (1991). Bud argues that neither of these approaches is comprehensive and he suggests a more coherent approach is achieved if biotechnology is placed in the historical context of the opposition between the competing claims of biology and engineering.

Such analyses, however, do not shed light on the common use of this term. Research into public attitudes and understanding of biotechnology must be interpreted in the light of what is commonly understood by this term. For instance, it is interesting that a recent survey of over 2,000 adults in New Zealand revealed that while 57 per cent of respondents had heard of the term 'biotechnology', only 9 per cent could explain what it meant. In addition, there is the volatility of this new and emergent branch of science and technology; the life span of many terms, including biotechnology itself seems to be short.

There is a general feeling in the industry that the word biotechnology has been over-used and is not specific enough to be of any value. Others complain that through both error and frequent use the word has become associated solely with genetic engineering (Kennedy, 1991, p. 218).

Scientific use of the term biotechnology peaked in the mid 1980s and has declined since (Kennedy, 1991). The current trend appears to be to defining the branch of biotechnology, thus, 'plant-biotechnology', 'marine-biotechnology', and so on.

The term 'genetic engineering', although often used interchangeably with biotechnology, elicits a stronger negative response in surveys (Bud, 1991; European Commission, 1993) and is, strictly speaking, a sub-discipline of biotechnology dealing with the direct 'transfer of genes from one organism to another' (Bud, 1991). Traverne (1991) argues that while biotechnology is 'as old as the hills', genetic engineering is a 'dramatic and fundamental' development. The attempt to 'sell' biotechnology as a long tradition of safe technologies has led to the decreased use of this term by the biotechnology lobby although it is still the favourite of the media and many consumer groups. Perhaps in an attempt to circumnavigate this confusion, the recent working papers by ASTEC (1993a, 1993b) have referred to 'gene technology' in an effort to refer to the technologies understood as genetic engineering (the 'science' of 'genetic manipulation) without the negative public and media reaction. The rationale for this seems to stem from the fact that 'gene technology' implies a collection of ('value-neutral') tools (that is, gene technologies) while genetic engineering and genetic manipulation imply a group of people (with vested interests and elite powers): genetic engineers.

For the purposes of this study we employ *biotechnology* as a generic term to indicate the broad base of technologies that involve the manipulation of life-forms. The specific term *gene technology* is used to indicate those modern technologies that directly involve the modification of genetic material.

Surveys of Public Perceptions of Biotechnology

There is an assumption that the better informed people are, the more likely they are to support the development of biotechnology:

> The technology, because it is often misunderstood at present, raises concerns in the minds of many people. While many scientists believe that much of the opposition to current applications of genetic engineering is misguided and misinformed, they are also keenly aware of the power of public opinion to bring about the imposition of regulatory constraints on their work so onerous as to make further progress impossible. Scientists accept that they need to explain what the technology is and what it can be used for. (ASTEC, 1993a, p. 7)

The importance of biotechnology for the Australian economy is stressed in a recent report by ASTEC (1993b). This report identified three features to be pursued: communication and public acceptance; a clear and efficient regulatory system; and, effective linkages between research and industry. As part of the effort by Australian scientists to communicate biotechnology with the public the CSIRO developed a travelling exhibition, 'Flying Pigs'. Alexander (1992) reported that 48 per cent of people (n = 2418) who interacted with a video survey in the exhibition responded *No* to the question *Is it right to interfere with nature?* A loaded question of this kind is likely to involve a negative response.

According to ASTEC, 'No broadly-based survey of public attitudes to genetic engineering has been undertaken in Australia' (1993a, p. 105). We need to rely on overseas data for our knowledge of public perceptions and understanding (For a table of surveys, see Zechendorf, 1994; Schibeci, Barns, Davison & Kennealy, 1994).

The first major survey focussed solely on biotechnology was initiated in 1986 by the Office of Technology Assessment (OTA, 1987) in the USA. This survey of 1,273 adults reported:

> The survey finds that while the public expresses concern about genetic engineering in the abstract, it approves nearly every specific environmental and therapeutic application. (OTA, 1987, p. 5)

Although respondents were generally supportive, they were also cautious with risks with applications to human genetics. In particular, the report noted that a majority appeared to be "willing to accept relatively high rates of risks to the environment to gain the potential benefits of genetically engineered organisms" (OTA, 1987, p. 4).

The largest surveys to date are the two Eurobarometer surveys conducted by the European Commission (EC). The fact that both surveys involve almost 13,000 people in twelve EC member countries also allows for a number of interesting international comparisons. The first, 1991, Eurobarometer (Marlier, 1992) aimed at finding out the level of understanding and awareness of biotechnology throughout the EC, as well as where they obtained their information and who they trusted to provide this information. Among the findings were: that 'genetic engineering' gains a less favourable response than 'biotechnology'; geographically, awareness declined moving from north to south; and, environmental and consumer groups were the most trusted sources with industry, trade unions, and political organisations the least trusted. The second Eurobarometer survey in 1993 (European Commission, 1993) allows for the first comprehensive analysis of how attitudes to biotechnology change with time (in this case the period 1991-1993). As with the surveys already mentioned, the 1993 Eurobarometer found that environmental organisations, consumer organisations and schools/universities were regarded as the most reliable sources of information, with less than 20 per cent of respondents regarding public authorities as a reliable source. Another European survey (of over 3,000 adults) concluded that their "poll findings demonstrate conclusively that the hysteria which surrounds biotechnology in some parts of the European Community is unrepresentative of public opinion" (Dixon, 1991, p. 16).

In the USA, a telephone survey of 1,228 randomly selected adult consumers was conducted in 1992 (Hoban & Kendall, 1992). In this survey, the term 'biotechnology' was used to refer 'to the use of biology to create new products or change existing ones" (Hoban & Kendall, 1992, p. 2). The survey was partly motivated by concerns that "the use of biotechnology in agriculture could elicit concerns similar to those expressed about agricultural chemicals" (Hoban and Kendall, 1992, p. 1). Among the findings were: 64% of respondents supported the use of genetic engineering in agriculture and food production; 71% reported that they believe that food biotechnology will benefit them directly; and, 66% of respondents wanted to learn more about food genetic engineering.

The Canadian Institute of Biotechnology commissioned a 'baseline' survey of 1500 Canadian citizens in 1993. The report stated:

> Public attitudes to biotechnology are still in their early stages of formation. The public is largely uncertain about what to expect from this technology, and there is little evidence to suggest that individual beliefs have yet to become politicised. (CIB, 1993, p. 2)

Interestingly, people were classified into three broad groups, depending on the balance of 'danger' perceived: (1) "more benefit than danger" (25 per cent of respondents); (2) "Middle of the road" (39 per cent); and, (3) "More danger than benefit" (24 per cent). This survey also reported that the media and government departments commanded the least trust.

doctors/nutritionists and university scientists the most. These findings are consistent with the Eurobaromter results.

Exploring 'Public' Perceptions

These public surveys provide some useful, but limited, information. The purpose of our project is to go beyond such surveys and to explore the perceptions of specific 'interested publics' to various applications of gene technologies. It employs methodologies which assume these 'publics' are not passive receivers of information, but active agents whose response to gene technology communication (or indeed any scientific information) is strongly influenced by their own 'life world' situations and background attitudes to the credibility of information emanating from scientific and commercial organisations. The project is thus being conducted within the framework of constructivist models of science communication which have been developed in the fields of education and social studies of science.

The project

The project so far has involved two major tasks. The first is a review and analysis of the literature related to gene technology, focussing on public understanding of the issues. The review includes national and international government and non-government reports and other relevant documents. A summary draft report of this literature review, which will be of interest to others working in the field, is now available (Schibeci, Barns, Davison & Kennealy, 1994).

The second task is to explore in greater detail the kinds of issues members of 'interested publics' are most interested in, with respect to developing gene technologies and the kinds of sources of information they find most useful. This was done through in-depth interviews in which respondents are able to make use of various categories of gene technology information contained within a HyperCard database, on a Macintosh Powerbook 180C. People were interviewed before and after they browsed through the HyperCard database, which contains ten categories of gene technology information, related to a particular food which is the product of gene technology. The pathway and time taken at each site was mapped. The choice of categories plus the responses made to the information and images will enable a more detailed exploration of public attitudes. Results will be compared with those of other large scale quantitative surveys. Interviews have been conducted with an initial group of 30 Murdoch students.

To enable us to explore issues in depth, we are preparing a series of case studies to use as stimuli during interviews. The first of the cases was based on the MacGregor's® tomato, recently released for sale in the USA.

MacGregor's® tomato

Macgregor's® tomato is a genetically engineered tomato grown from Flavr Savr™ seeds. Currently, tomato growers pick their tomatoes green and hard, in order that they are not overripe by the time they reach the consumer, and also to ensure that the percentage damaged and destroyed during transportation is minimised. These tomatoes are ripened by gassing them with ethene (ethylene), which mimics and so triggers the fruit's built-in ripening mechanism. Thus, "the fruit resist damage during harvest, transport and marketing and have extended shelf lives" (Deeker, 1994, p. 24). The advantages have been summarised in this way: "a field can be allowed to obtain more colour before harvest and provide for fewer losses due to immature green fruit, yet not suffer losses due to rot in the field and product loss during shipping" (Redenbaugh, Hiatt, Martinueau, Kramer, Sheehy, Sanders, Houck, & Emlay, 1992, p. 18).

The growers' main concern is to improve profit margins, not produce the most tasty tomatoes. Many people, from home cooks to professional chefs believe that vine-ripened tomatoes taste much better the normal (gassed) tomato that appears on supermarket shelves for most of the year. This is because "natural fruit ripening is complex process involving coordinated biochemical changes of sugars, acids and volatiles necessary for taste and aroma" (Deeker, 1994, p. 24). A US Department of Agriculture consumer-satisfaction survey rated tomatoes "dead last" (Van Brunt, 1992, p. 748) out of 31 items. Researchers at Calgene Fresh (the Californian division of Calgene Inc.) believed consumers would pay more for products which look and taste better and last longer: thus the Flavr Savr$^{\text{TM}}$ seeds.

The Flavr Savr$^{\text{TM}}$ seeds are engineered by a patented process which uses "antisense RNA technology to suppress the production of a softening enzyme, polygalacturonase (PG), which attacks pectin in the cell walls of ripening fruit" (Van Brunt, 1992, p. 748). Olempska-Beer, Kuznesof, DiNovi & Smith (1993) noted: "An antisense gene is a gene with reversed orientation with respect to its regulatory sequence"; antisense RNA is that transcribed from an antisense gene" (p. 67). By placing the gene in an antisense orientation, PG is almost completely removed; that is, the gene is switched off. Calgene's research indicates that this trait is stably inherited. This allows the MacGregor's® tomato (a manipulated variety of *Lycopersicon esculentum*) to be left to ripen on the vine for longer than other tomatoes, because of its extended shelf life. Normal ripening is associated with increased ethylene production and other complex chemical processes which produce the taste of a naturally ripened tomato.

The end result is that the MacGregor's® tomato "remains firm and sweet for 7-10 days longer than ordinary tomatoes without refrigeration or the use of ethylene gas" (ASTEC, 1993a, p. 16). The mechanism by which the antisense gene is added to the tomato DNA is the commonly used vector, *Agrobacterium tumefaciens*.

Calgene requested that the US Food and Drug Administration (FDA) conduct a safety and nutritional review of the tomato. Tomatoes naturally contain low levels of the toxic alkaloids, *tomatine* and *solanine*. Calgene conducted tests to ensure that the levels of these toxins in Flavr Savr$^{\text{TM}}$ seeds were within the range of natural variation for cultivated tomatoes (Redenbaugh et al, p.25). The testing was rigorous and FDA approval of the tomato was not disputed by any party on the grounds of the data; however, testing was only conducted because Calgene wanted to reassure the public. Testing was not mandatory because the tomato was "substantially similar to existing foods". Testing is only required in the USA if foods contain "new constituents that raise significant safety questions" (Redenbaugh et al., 1992, p.25).

We constructed a multimedia package, based on HyperCard, which summarised information about MacGregor's® tomato into ten categories: science, marketing, business, ethics, politics, human health, environmental impact, regulation, history and production.

Preliminary Study

Method

We called for volunteers among students who would have some interest in biotechnology. Each volunteer was interviewed individually. Respondents were first asked a series of questions about their understanding of biotechnology, whether they were aware of any products that have been the subject of biotechnological research or have been released, if there are any aspects of tomatoes they normally buy that they would like to change and what their response would be if they saw the new, genetically engineered tomatoes in the supermarket. They were then asked to rank ten information categories in the HyperCard stack from 1, the *most important* to 10, the *least important*, from their personal perspective.

They were then given a short introduction to the computer and had 15-20 minutes to explore the HyperCard stack with the information on MacGregor's® tomato; they were free to investigate the categories in any order they like in the time allotted. They had a sheet on which they noted comments on each category they consulted. They were informed that they are not expected to look at all the categories, and that they could return to any they have already examined. Once they completed the tour, they were asked to re-rank the ten categories (the first ranking sheet was not available to them), and then asked some further general questions regarding their views about biotechnology. The pre- and post- interview questions were recorded on audiocassette for future transcription and analysis by the NUDIST software (Richards, Richards, McGalliard, & Sharrock, 1992). Interviews lasted between 45 and 60 minutes.

We also had the opportunity to discuss MacGregor's® tomato with a group of nine market gardeners, who were tomato growers, at a meeting in Wanneroo.

Thirty students, all volunteers, were interviewed. Nineteen were enrolled in the biotechnology programme at Murdoch University: eleven in the first year, two in second year and six in third year. Nine were in a science teacher education programme and two in a science-technology-society unit. Of the thirty students, twenty-five were female.

Results

Ranking of Information Categories

Science, not surprisingly, given the background of the sample, was the category of information which was ranked 1, *most important* by most (12 of the 30 participants): in fact, after the HyperCard browsing, 14 respondents ranked it the most important category. The next most important category of information was *health* (ranked first by nine respondents, both before and after browsing.

At a meeting with market gardeners at Wanneroo, the categories *environment*, *science* and *marketing* were nominated as the most important categories.

Initial responses

Respondents were asked, *What's your understanding of biotechnology?* The meanings associated with *biotechnology*, according to the public surveys reviewed above, are varied, and so we began our interview by giving students the opportunity to tell as what they understood by the term. Despite the science background or interest of students in our sample, seven of them had very little idea about what biotechnology meant. For example, one said:

> Well technology is, you know, instruments and stuff like that, and Bio is sort of like, biology, so I suppose it is something to do with technology concerning biology. Or you know, developments in that respect.

Another said: *I suppose it means biology used in technological areas. The use of biology to advance technology.* Others had a view that it was connected with 'superhumans', eugenics, IVF or cloning. Nine had a view which biologists would characterise as 'partially correct'; for example, *It is sort of the scientific manipulation of genes to learn about technology, that we see is useful to us.*

Six articulated a view which is in accord with modern biology. For example, one indicated some biotechnology work in this way:

> You do genetic engineering, you do the molecular side of things, you do processes, such as a product. Products such as antibiotics and pharmaceuticals as well as bio processes like vinegar production and beer and stuff like that.

To some extent, the variety of meanings provided by the respondents reflects the variety of ways in which the terms *biotechnology* is used. Its historical association with brewing and cheese making is acknowledged, as are some of its more recent manifestations, most precisely characterised as 'gene technologies'.

Five said they had not heard much about biotechnology. Seven said they had heard very little; one of these noted:

> The only time we hear about it is when something goes wrong. If there is an accident or if something gets out of control. Or someone comes up with a theory that something that is going wrong in the world was caused by outbreaks from some sort of science. I first heard about it when I came to Murdoch's Open day and they said, "You can make beer," and I said, "Good," and that's it. No-one has ever heard of it. When you say 'biotechnology' they don't understand what it is but when you say something like 'genetic engineering', then they understand what part of it is about.

The remainder said that they had heard about the area. They cited the mass media as a primary sources of their information: *last night if you watched the ABC.... on* Lateline *there was a talk about genetic engineering, of the Science of Australia and the Future.*

Respondents believed that there has been increased media coverage about biotechnology, especially since the film *Jurassic Park* was released. One observed of this coverage:

> I think the media sensationalise it a lot, but, um, some of the things are positive like in *The Australian* they had an article a couple of weekends ago about the new sort of stuff going on and some of it is positive.

Almost without exception, respondents said they would like to know more about biotechnology, especially applications. One noted that she looked forward to a news item: *Microbiologists have discovered a new way to make shoelaces!* When they were asked to nominate examples of product which have been the subject of biotechnological research, a range of responses was given. Five were unable to cite an example, or were very vague. The remainder were able to cite examples such as disease-resistant crops and vaccines produced by genetic engineering. One said :

> Well, I guess it is all the antibiotics. I mean that is with biotechnology. Pesticides. Probably the wine, or the fermentation industry, could be where you have got biotechnology. Germ warfare. Warfare is another one. I mean, there is some discussion about that and cattle breeding – Biotechnology breeding. Or any sort of animal breeding. Artificial insemination. Those areas.

Our next questions focussed on the tomato. When asked, *Are there any aspects of the tomatoes you buy that you would change if you could?* fourteen said they would not. Improvements suggested by those who wanted changes included more flavour, firm texture, longer shelf life, redder colour and larger size. One was quite emphatic about currently-available tomatoes: *I think that they are tasteless.* One respondent was adamant that tomatoes should not be tampered with :

> Well I am funny really because I am a great lover of science. I mean, that is my area: I am Physics major. But at the same time there is this part of me that likes to keep things natural. You know, it is a real contradiction, really - but, no, I wouldn't really change anything. I would let nature take its course, I suppose. I don't like apples being sprayed with wax and I don't like using insecticides. So any bit of fiddling really, I am not really very keen about.

Respondents were then asked to commit themselves to a decision if the MacGregor's tomato were available for sale. As expected, some were positive (if cautious), others negative while yet others would try them, but were happy with current tomatoes. The possibility of unforseen long-term consequences was among the reasons for negative views; for example,

> It is too new a science to begin to just freely, just start throwing genetically engineered organisms or plants. You have got to study it really carefully because if you do something wrong, right, and then you know, later ten years down the road you get all these people with cancer and all that, then you would be in the *shit*! You know, so caution.

Following this initial set of questions, respondents were given 15-20 minutes to browse through the stack.

Post-HyperCard Browsing Responses

Sixteen said their views had not changed; however, they said that they had become aware of the issues raised in the database. For example, one said

> Ethics, I have always been very concerned about and there is a lot more ethical issues there than the ones I had thought of. I had only thought of fairly basic ethical issues and they just go right through the entire industry. I had never thought about it from the point of view of a grower or a marketer, or anything like that. I suppose I tend to consider either just from a health point of view. I have just never really considered the poor people who were involved.

Of those who had changed their views, some said they were more likely to try it, some less likely:

> Well, first of all I would be very eager to taste them. Wondering what they taste like but there will be a bit of hesitation. Just this wondering, "Have

> enough tests be done?" Can you provide evidence that there has been proper testing . . . ?

Views on labelling of genetically altered foods varied. Some stated that the label should read *This has been bio-engineered* for reasons of "fairness" and, in the words of one of the respondents

> I think people at this early stage need to have a choice of whether they want something because a lot of people are frightened by it. So I think that they need to be at least told, even though their fears are unfounded, I still think that it needs to be told that this is a genetically engineered, you know, genetically altered plant.

Three took the view that, if the tomato were safe, there would be no need for labelling. Some believed that testing in the USA was not sufficient; there should be additional testing in Australia, because they believed Australia standards were higher than those in the USA.

Discussion

The study of the public understanding of science and technology is a burgeoning field of inquiry. In Australia, there is the Science and Technology Awareness Programme under the auspices of the Federal Department of Industry, Science and Technology, as well as the Royal Australian Chemical Institute's sponsorship of the *Understanding Science and Your Environment* Programme. The Centre for Science Communication, University of NSW and the Cooperative Research Centre (CRC) for Plant Science have both held forums this year, which have included talks on public perceptions of the biotechnology industry. The Australian Institute of Ethics and Professions recently held its first national conference on genetic futures. In the U. K., there was the Royal Society's (1985) report, and in the U. S. A., the AAAS (1989) has published *Project 2061*.

Among the areas with a significant science/technology dimension is 'biotechnology'. Analysis and debate around the public understanding of biotechnology (PUBT) seems set to develop very rapidly over the next few years. The broader study, the public understanding of science and technology (PUST), is already well underway and provides an important analytic framework for considering particular issues surrounding biotechnology. The relative claims of the 'cognitive deficit' and the 'interactive' approaches, the two poles around which this debate seems centred, need to considered (Layton, Jenkins, Macgill & Davey, 1992). It is argued that the 'cognitive deficit' approach is already established (often implicitly) within some government, industry and scientific approaches to PUBT and underlies the majority of quantitative (survey) data. This approach clearly needs to be balanced with more contextual methods of obtaining quantitative data.

The 'science' of biotechnology offers a particularly striking example of the diverse interests that can converge under the banner of PUST. Biotechnology is equal parts of pure research and commercialisation; business and government regulation; science and technology; and so on. Industry is concerned to develop products that the consumer will purchase. Government is concerned to minimise social risks and maximise social (economic) benefits. Scientists are concerned to ensure broad support and funding for their research. Many community groups are concerned to ensure that risks are openly and widely debated. In all these ways, study into PUBT is of more than academic interest; it is both inherently interdisciplinary and situated within a volatile social debate. It is clear that biotechnologies are going to be a major element in social change over the next couple of decades and, just as clearly, public understanding and debate about biotechnology is a crucial element in directing this change toward broad social benefit.

One respondent's comments reflected the caution expressed by others: *Biotech has enormous potential, however must be applied with caution, as it is also potentially (extremely!) hazardous.* More specifically, the answer to the question posed in the paper title, *Would you eat a genetically engineered tomato?* according to one third year biotechnology student, is:

> Yep, but frankly speaking I would never buy a genetically engineered tomato if I *knew* about it until such-and-such a time as like maybe twenty years from now when, you know, it has been proven to be safe.

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TEACHERS' VIEWS ABOUT TEACHING ANALOGIES IN A SYSTEMATIC MANNER

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The Need for Analogical Instruction Informed by Research

A useful working definition of an analogy is that it "is a correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas" (Glynn, Britton, Semrud-Clikeman, & Muth, 1989, p.383). Simply stated, an analogy is a process of identifying similarities between two concepts. One concept, which is familiar, is referred to as the *analog* and the other concept, which is unfamiliar, is called the *target*. Usually the target relates to the scientific concept. In using an analogy in science teaching, teachers should select a student world analog to assist in the explanation of the content specific target (or topic). The analog and target share attributes that allow for a relationship to be identified and contribute to the knowledge base of teaching. However, there are features of the analog which are unlike the target and these can cause impaired learning if incorrectly matched. Nevertheless, the use of analogies does not always produce the intended effects, especially when teachers discover that students take the analogy too far and are unable to separate it from the content being learned. Some students only remember the analogy and not the content under study, while others focus upon extraneous aspects of the analogy to form spurious conclusions relating to the target content.

Research suggests that analogies are not used by science teachers as often as might be expected (Dagher & Cossman, 1992; Treagust, Duit, Joslin, & Lindauer, 1992; Thiele & Treagust, 1991), in spite of the existence of useful analogies in textbooks (Thiele & Treagust, 1993; Thiele & Venville, 1993). In addition, when analogies are used in class they are frequently not presented in a manner which enhances their effectiveness. As the vast majority of science teachers have no formal training in the use of analogies, it is not surprising that so little use is made of them.

Given the lack of opportunities for teachers to learn about analogy use, one proposal is to offer inservice activities which deal with the issues presented in this paper. If analogies are to be used effectively by science teachers, then a carefully planned pedagogy is called for, within which the analogies used are relevant to as many students as possible. In researching the literature we identified a number of models or teaching approaches for reliable and valid use of analogies in classroom instruction. Subsequently, we provided inservice with Glynn's (1991) Teaching-With-Analogies model for seven teachers, recorded their teaching and their reactions, and in some cases those of their students (see for example, Harrison & Treagust, 1993). As might be anticipated from the competent teachers with whom we are working, they interpreted the Glynn Teaching-With-Analogies model in their own way and further modified the teaching approach for incorporating analogies into their science teaching. The resultant teachers' use of Glynn's model and our own analyses of that teaching has enabled us to develop a simpler and what at this stage appears to be a more effective and efficient three-phase model of analogy teaching.

A Systematic Manner of Teaching Analogies

In teaching with analogies, teachers initially considered the concept to be taught (was it difficult, unfamiliar or abstract?), whether or not the students already knew something about the target concept, and whether or not the students were familiar with the analog. This *Focus* on analogical instruction took place both before and within the early part of the lesson, depending upon the circumstances. During the class presentation of the analogy, teachers paid careful attention to the likes and unlikes of the analog and the target, discussing both features of the analog and target and drawing similarities between them as well as ways the analog and target are not alike. We have called this the *Action* phase of analogical teaching. Following the presentation of the analogy, teachers reflect on the clarity and usefulness of the analog and consider ways in which the analog may be improved. This *Reflection* phase may take place within the lesson itself or after the lesson as later preparation occurs. We have observed that in practice these phases are not distinct but run into one another.

FOCUS		
	CONCEPT	Is it difficult, unfamiliar or abstract?
	STUDENTS	What ideas do the students already have about the concept?
	ANALOG	Is it something your students are familiar with?
ACTION		
	LIKES	Discuss the features of the analog and the science concept. Draw similarities between them.
	UNLIKES	Discuss where the analog is unlike the science concept.
REFLECTION		
	CONCLUSIONS	Was the analogy clear and useful, or confusing?
	IMPROVEMENTS	Refocus as above in light of outcomes.

Figure 1. The three aspects of the FAR guide for teaching and learning with analogies

To assist teachers in analogical instruction in a systematic manner based on our research, we have produced a guide for teaching and learning science with analogies. In doing so, we use the three phases of the teaching approach, *Focus, Action* and *Reflection*, to form the acronym FAR (see Figure 1). The purpose of the FAR Guide is to help teachers maximise the benefits and minimise the constraints of analogies when they arise in classroom discourse or in textbooks. The guide has come about as a result of many hours observing and interviewing teachers and students and has been designed, as much as possible, to reflect the skilled way in which an exemplary, practised teacher uses analogies in their teaching of science. The phases of the FAR Guide have become second nature to those teachers who have been familiarised with them and they have been usefully applied to the teaching of analogies. Most of all, preliminary research with the FAR guide indicates that teachers and their students benefit from, and enjoy analogies when teaching and learning science.

Teachers' Perspectives and Queries about the FAR Guide

Subsequent to its development, copies of the FAR Guide were given to three teachers who had participated in the initial trailing of the Teaching-With-Analogies Model. The teachers were then interviewed in order to ascertain their perceptions of the FAR Guide, in particular what they thought about its format, whether they felt they could incorporate the FAR Guide into their teaching and whether they had any questions or suggestions with regard to the FAR Guide.

Format

> I think because it's set out into three groups that makes it easier to then remember the points that come in between. Whereas because this [TWA] is just six steps, I don't know, I'd probably think, well what was the first step? Whereas this [FAR] I think has really picked up on, you know, classifying them into three groups and you think well focus, what do I think about before I give the analogy to the kids and then when I'm actually using the analogy, similarities, [differences]. I think that's good. I know when I looked at it I thought this is a much more organised way to remember it. And once again it's logical, its not that different to what we were doing.

Generally, the teachers felt that the format of the FAR Guide was clear and would be easy to work with. They said that the three major parts, Focus, Action, Reflection, would provide teachers with an organised way to remember the FAR Guide and facilitate recall of the parts in between. Another perspective was that the FAR Guide was logical, because it represented what good teachers do anyway. The teacher quoted below said that the FAR Guide covered the vital steps for teaching with analogies.

> Yeah, well I think to use the analogy they're the vital steps that you have to do, like you have to sort of keep referring and keep explaining the similarities and then you've got to say well, although it's similar most of the time, it's not similar all of the time.

Implementation

All three teachers felt that it would be easy to incorporate the FAR Guide into their teaching and two teachers felt that other teachers also would be able to. The third teacher felt that it would be possible for teachers to put the FAR Guide into use in the classroom, but it would require practice for them to utilise it properly. It was suggested that the three phases of the guide, before during and after the analogy, would make it easy to include in their teaching. One teacher said she uses a lot of spontaneous, unplanned analogies in the classroom, but with practice she felt she could use the guidelines of the FAR Guide to improve the potential of these analogies.

The discussion generated by the following queries from teachers has been incorporated in the introduction to a booklet of suggested analogies which was made to accompany the FAR Guide and is the focus of in-service workshops on using analogies in science teaching which have been presented by the researchers.

When and by Whom Are Each of the Stages Carried Out?

A common question about the FAR Guide concerned the first (focus) and third (reflection) stages. The teachers wanted to know whether these parts were supposed to be done in the classroom with the students or by the teacher as preparation or revision outside classroom time. In response, the only part of the FAR guide which is essential in the classroom at the time of use of an analogy is the Action stage, that is the clear discussion of the similarities and differences between the analog and target concepts. It is possible for teachers to do the Focus and Reflection phases out of the classroom or with the students, it very much depends on the teacher's teaching style, the content, and the analog in question. However, it is desirable for teachers to determine the familiarity of the analog to the students and to come to conclusions about the analogy in collaboration with the students themselves.

Student Familiarity with the Analog

Other questions concerned student familiarity with the analog. How well should students know about the analog? and should all the students be familiar with the analog? Optimally, all students in a classroom should be familiar enough with the analog situation to make reasonable and informative conclusions about the target situation. Discussion or demonstration of the analog may be required by the teacher and is to be encouraged.

Training the Students to use Analogies

Some form of training for the students about analogies, why they are used in science and their advantages and disadvantages, was thought to be very important by one teacher. This was something that the teacher felt was not explicitly addressed by the FAR Guide. In light of other research (Venville, Bryer & Treagust, 1994) it is valuable to train students in the use of analogies in order to highlight the limitations of analogies, however as this can be a one-off procedure for each class, its incorporation in the FAR Guide would be inappropriate.

Teachers' Views from Workshops

During 1992 and 1993, we conducted several workshops at national and state conferences and afterwards collected comments from the teachers about the workshop and particularly about the FAR teaching approach to analogical instruction. The summarised responses are presented in Figure 2. The perspectives expressed and views given are very similar in many instances to those of the teachers interviewed above.

Teachers' Views of their Practice with the FAR Guide

Four teachers who had taken part in an in-service program with the FAR Guide were observed teaching science with analogies in their classrooms. Subsequent interviews with the teachers about how they perceived the FAR Guide had affected their use of analogies revealed the following points.

Confidence and enthusiasm

Teachers felt encouraged and had increased confidence in the validity of using analogies as a pedagogical tool after they had been through the in-service program.

> Things like that are good because they [the FAR inservice guide], if nothing else they confirm that what you're doing is the right thing. Perhaps for someone who is just staring out teaching you know, it might have been a bit more sort of revealing. But I still found it really good from the point of view, well, you know, I do a lot of that sort of thing and when people do research and confirm that there's actual psychological or statistical research to back up that is a good way of doing things then you find that encouraging. And I picked up some extra sorts of analogies or modifications of ones that I do.

Sharing teaching ideas
Good to share ideas (2); I would like to have spent more time listening to other people's analogies; I like the interaction in small groups. (3); Nice to get a few ideas from other teachers (3)

General
Would like to get more simple analogies to use (2); Very useful; Very impressive - it has made me more conscious of how I use analogies; As a first year teacher, it has encouraged me to think about and utilise them more in the future. (2); Focussed on appropriate use of strategy for my own use of analogies (3); Excellent workshop (4)

Analytical
Useful to focus on what makes a good analogy; Made me realise that analogies are used more often than I believed (2); Great to see some research being done on this; Great to add analogies to existing repertoire, also good that they are already analysed; Very worthwhile to make me think about what I use and what I do when I do these things spontaneously in class without planning and thinking about them before hand; It was useful to see these skills we take for granted broken down into their components. Now we can work out why our successful analogies work and others do not; Would like to have some of the inadequacies of analogies pointed out; It made me more aware of the importance of analogies in teaching - especially that students [need to] understand the analogy being used; where do analogies stop and other teaching strategies start?; Can you divide your analogies into models, practs, acting out, imagining, role plays, etc?; FAR Guide – good for assessment of usefulness of analogies.(5); I hadn't previously considered that analogy is most useful if the concept is difficult, or how familiar are the students with the analog.

Need for a Handbook
Would love to have a collection of analogies used by science teachers; A hand book on well used and successful analogies would be useful as a teachers' resource –perhaps listed under curriculum headings (3).

Advice offered
Analogies should only be used when problems in understanding are encountered; Be EXTREMELY careful in the choice of analogy; Be aware of the limitation of analogy; The need to use analogies and the possible number of options used depends heavily on the understanding of the students in the first place and how quickly they pick up the concepts and result of situations that arise.

Perceptive comments
What is the difference between a model and an analog?; I realise that I use analogies in my teaching but I have called these models. Does your guide need to clarify this?; Discovered that I don't often focus on UNLIKES (2); Strong connection with a literacy-based approach to science teaching and often results in students creating their own analogies which perhaps are even more powerful than teacher-created analogies.

Figure 2. Responses from participants (n=32) in a FAR analogical instruction workshop, Muresk, 1992

Over-emphasis of the Analogy

Initial interviews after the in-service course revealed that teachers felt that they tended to over-emphasise analogies they used, especially when being observed. This is to be expected and, as the teacher quoted below indicates, they are aware of this problem and therefore, in time and when not being observed, this over-emphasis should disappear.

> I guess maybe, I'd probably myself, I felt that I might have over done it even with the analogy type and might have repeated myself in saying well, you know, see how similar these two things are just because I knew that I was being scrutinised.

Student Familiarity with Analog

One of the most important parts of the FAR Guide, according to the teachers, was establishing student familiarity with the analog.

> I think the most important thing in the FAR Guide, is where the students have to relate to the analogy. If you introduce another analogy where they are not familiar to it you're just confusing the issue. Because first of all they don't understand the concept you're trying to teach and secondly they don't relate to the analogy you're using. So it just compounds the confusion.

Establishing student familiarity with the analog was something all the teachers interviewed felt the FAR guide caused them to do more carefully. For example, one teacher scrutinised her regular teaching notes more critically and discovered a regular teaching analogy she used was inappropriate.

> I hadn't stopped to think, well, how much do the kids relate to butter menthols [analog] any more. I was just happy to go along with it because it was in my notes and that's what I was going to use to explain it.

Another teacher became aware that the car system analog he uses for homeostasis may not be familiar to some of his female students, so during the lesson he carefully explained the analog and checked their understanding.

> One thing in doing it I was concerned about the sort of gender side of things, just how familiar perhaps some of the girls would be with the function [of the car], that's why I did a very brief, well these are the four key elements, the engine, the radiator, the thermostat and the water pump.

Delineating Likes and Unlikes

One teacher said that the FAR Guide, particularly the action phase, guided her to focus in on the main points of the analogy. To be clear and explicit about the similarities and differences between the analog and target gives teachers and students a strong base from where further learning can take place.

> And this is good too [action stage of the FAR guide], because if you're going to use an analogy effectively, something I learnt from the steps that we did before was the actual information and you can say it's like a charged battery [analog for ATP] and these are the things it does. You can focus in on the main points. So that helps you to do that.

Reflection

Reflection on the analogy and its perceived success was evident in the teacher interviews. The teachers seemed to be critical of analogies and the way they had used them with views for modification and improvement

> There were a couple of points I thought afterwards or before and afterwards that I could have done to improve it. So if I was going to do it again I would include a couple of those elements in there.

Teachers' Content Knowledge

Using an analogy out of her major area of expertise made one teacher feel uncomfortable because she was not confident of the science content being covered. Even though the teacher had discussed the analogy and science concept with a colleague she found that probing questions from the students were difficult to answer. In this situation the teacher may not have had enough content knowledge to clearly delineate the limitations of the analogy.

> I actually found the train one (analog for electric current) difficult to use. I know I'd sort of look at this part of the train and think what's that got to do with it? The

> sand on the track, the kids asked me questions about, well if it's slowing down there the whole set of carriages are going to be slowing down or is it just that little bit there, and I don't know.

Another teacher, on reflection on his own teaching, also expressed concern that using an analogy without adequate background knowledge would compound the problem.

> Well one thing I'd like to say. I don't know if it came out in the FAR Guide, but I would say that it is essential for any teacher using an analogy to fully understand what it is that they are trying to explain. ... That is the danger isn't it. That is the danger that a teacher that feels like they're on shaky ground will resort to an analogy to say well that will help me understand it, right, but if there's a gap in their knowledge they're not going to fill it with an analogy they're just going to compound it.

Summary

The research program on analogies (Treagust, 1993) commenced because we were interested in the use of analogies in teaching and learning, and also finding out how this research could be used to inform practice in a meaningful way. To this end we have enjoyed the opportunity to observe and learn from many teachers who have used analogies in their regular teaching and who have been willing to implement the new approaches described in this paper. The perspectives and queries of teachers who helped trial the FAR approach and the views of other teachers who attended workshops and those who have used the approach in their classrooms have given us confidence that we should continue our endeavours.

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ARE STUDENTS' WORLD VIEWS AFFECTED BY SCHOOL VIEWS: A SOCIOCULTURAL PERSPECTIVE

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Background and Rationale

At times the teaching and learning strategies adopted in the high school classroom can be perceived as being in conflict with the natural learning strategies of the learner. Teachers can use practices that may inadvertently conflict with students' previous learning patterns, home environment, mores and values. High school classrooms are increasingly reflecting a greater range of students with different cultural backgrounds. Many teachers have failed to realise that a number of their students may come from communities with widely differing cultural practices. Many fail to realise that even within an ethnic grouping that there are different cultural practices and beliefs. Just as there are differences between families in how they train their children, so there can be differences between regions within an ethnic or tribal grouping. Consequently, there can be a complete lack of sensitivity to the important cultural milieu into which the teaching and learning are to be placed. We accept Geertz's (1973, p. 5) definition of culture as:

> man is an animal suspended in webs of significance he himself has spun. I take culture to be those webs, and the analysis of it is not an experimental science in search of law but an interpretative one in search of meaning.

It follows that unless students can relate the application of what is taught to their own cultural background, then the teaching strategies are likely to be less than effective in enhancing their learning. For some time now, it has been argued that one of the main sources of students' learning difficulties is the lack of optimisation between teaching strategies utilised by the teacher and the natural learning styles of the learner (Hofstein, Giddings & Waldrip, 1994; Kempa & Matin-Diaz, 1990a; 1990b). Trueba (1988) argues that while sociologists have made considerable progress in explaining the relationship between instructional strategies and the learning process in their examination of the differential achievement of minorities, they have often ignored the critical role of culture in this relationship.

Walberg's (1981) model of 'educational productivity' suggests that nine factors require optimisation in order to increase affective, behavioural and cognitive learning. These causal influences on student learning include a set of aptitude variables (Ability, Development and Motivation), a set of instructional variables (Quantity and Quality) and a set of environmental variables (Home, Classroom, Peers and Media). Waldrip and Giddings (1994) argued that a fourth set of variables (Culture) should be included for the optimisation of the learning process. This study will build on this theoretical base. As Zaharlick (1992) implies, educational productivity can only be optimised when the context is accounted for. We argue that learning can only be optimised when the cultural context of the learners is accounted for. We agree with Trueba (1988, p. 282) that "the conditions for effective learning are created when the role of culture is recognised and used in the activity settings during the actual learning process".

For example, while working in a developing country (as defined by the World Bank), even though we view all countries as developing, a professor of geology from the local university once informed one of us that he believed in both evolution and special creation as viable explanations of origins. In response to the suggestion that there was a disparity between these two explanations, he explained that he believed in evolution when he was at work and in special creation at church. After some discussion, he saw no disparity between the two viewpoints. We believe that this example typifies the assertion that many learners hold simultaneously two different viewpoints that provide disparate explanations of naturally occurring phenomena: a 'world view' and a 'school view'.

In relation to science education, we define 'school view' as the canonical scientific conceptions and methods of inquiry that science teachers endeavour to enable students to develop in order to understand the physical world. Cobern (1991, p. 7) defines 'world view' as the foundational beliefs about the world that support both commonsense and scientific theories. We have adopted a restricted version of Cobern's definition, namely, that the 'world view' refers to the totality of experiences and explanations that have been built up prior to any experience of school instruction and that comprise students' preconceptions of natural phenomena. We are concerned that a disparity exists between students' world views and the official school view, especially in school science where Western explanations of natural phenomena can be very different from traditional explanations. In our experience of science teaching in developing countries, many teachers try to enforce the school view while failing to recognise the existence of students' world views. In cases where major disparities exist between students' world views and school views, we believe that students' learning becomes fragmented and lacks cohesiveness and personal meaningfulness. An examination of this disparity was one of the goals of the study reported in this paper.

In many developing countries, the official school view is a product of Western culture inasmuch as the local education system remains tied to its original source (Kahn, 1990). In particular, science programs often are taken directly, with little or no adaptation, from Western nations' science programs (Ingle & Turner, 1981; Ogawa, 1986). We believe that, in developing countries, school science instruction that is based faithfully on imported curricula is likely to result in a disparity between students' world views and their school views. In these contexts, culture and traditions tend to be largely 'people-based', whereas science is based largely on 'things' (Ogunniyi, 1988). When learning science, this difference in emphasis can produce tensions which result in students developing two different sets of values and attitudes (Kay, 1975) leading to a conflict concerning which set of values and attitudes should be adopted. A consequence of this conflict is 'compartmentalisation', that is, students adopt two, sometimes conflicting, explanations of a particular phenomenon. One of these explanations is based on traditional village explanations or experiences and the other is based on what is taught in school.

We feel that it is important to examine the relationship between students' world views and school views because, as Gilbert, Watts and Osborne (1982, p. 64) argue, the "dominance of the students' prior understanding . . . [can] often lead to quite unintended interpretations of what is being taught". The epistemological framework of Gilbert et al. concerning 'prior understanding' was based on Schutz and Luckmann's (1973) foundational theory which argues that the learner tends to typify experiences in order to create meaning structure. Assimilation of these typical experiences forms a 'life-world knowledge' that is both acceptable and persistent. Berger and Luckmann (1966) argue that this intuitive life-world knowledge is constructed during students' early childhood socialisation and enculturation by 'significant others' (e.g., parents and peers). However, in the context of science education, the secondary socialisation process of school science involves less subjective inevitability, and may be experienced as being less compelling (Solomon, 1987). As Banks (1993) argues, "the ethnic and cultural experiences of the knower are also epistemologically significant because these factors also influence knowledge construction, use, and interpretation" (p. 6).

The cultural background of the learner may have a greater effect on education than does the subject content, especially in relation to students making observations in science classes (Jegede & Okebukola, 1991; Okebukola, 1986). Based on experience, however, we believe that while students may be somewhat selective about making observations, the real issue is that students are selective about the relationships between their observations, rather than the observations per se. This assertion reflects the contention of Falgout and Levin (1992) that, for developing country students, the importance of knowledge lies in its application, results and products, whereas Western schools tend to regard as a virtue the learning of knowledge for knowledge sake. From an epistemological perspective, therefore, it is important that teachers have an "understanding of traditional modes of belief about the natural world" (Ingle & Turner, 1981, p. 362). We argue, that unless students can relate the school view of the natural world to their own well-established world views then teaching strategies are likely to be less than effective in enhancing the permeability of students' world views to their school views.

Purpose(s) of the Study

Comparatively little research has been conducted into the state of multicultural high school classrooms which contain students with a diverse range of cultural backgrounds. The paper attempts to explore some of this gap in the research by briefly describing an ethnographic-interpretive study based in Melanesia which examines the permeability of students' world-views to the official Western school view. Melanesia is composed of many sub-cultures, some of which are inherently different even though the region has some ethnic commonalities. In an integrative review of research on the effect of culture on the learning of science in non-Western countries, Baker and Taylor (in press) concluded that attempts to nationalise Western science curricula are likely to be ineffective because of the disconnectedness of students' world views and school views. Whereas that study focussed on the influence on learning school science of students' cultural backgrounds, including their language and traditional beliefs, this study reversed the focus and examined the prospects of school science making a significant contribution to local cultural practices. We set out to examine empirically the permeability of the world views of students of school science in a developing country in relation to their school views.

Design and Procedures

Because of the extensive first-hand experiences of the first author within a range of Melanesian cultures, we planned to conduct an interpretive-ethnographic study (Erickson, 1986; Hammersley & Martin, 1983) that involved field work in a developing Melanesian country. We chose an island located in a small South Pacific Melanesian country that we call 'Kantri' (a pseudonym is used because of the political sensitivity of the study). Because the first author had previously lived and worked in Melanesia for 10 years he was well-known and, therefore, was readily able to gain access to key people both within the school system and at a local level.

By means of interviews conducted over a two-week period, we had planned to learn about: (1) traditional world view explanations of selected natural phenomena held by local Melanesian school students and their parents; (2) students' school view explanations of these phenomena; and (3) students' and parents' perceptions of the viability of the school view within the context of their daily lives. On the basis of this understanding, we hoped to be able to determine the extent to which traditional world views are influenced by school views. In keeping with the interpretive-ethnographic tradition, as we became more sensitive to the local culture we learned that our research design needed to be modified. Within a short time after arrival in Kantri, field work enabled us to learn more about the nature of the local Melanesian culture and, consequently, we refocussed our research questions.

We had intended to seek explanations of a range of natural phenomena which, from our experience, form an important focus for traditional stories in many Melanesian cultures. However, the distinctiveness of the local culture of Kantri caused us to reconsider the focus of our questions. Some expressions describing natural phenomena had no local equivalent translation and some phenomena did not have a place in the local lore and traditions.

Village Elders

Parents of students were not interviewed as initially planned because the villagers desired to show respect by making available village elders for interview. Village elders are perceived to be the source of all wisdom and are the recognised authority on tribal knowledge. Contact with three elders was made through a respected local high school principal who was related to two of them, Laki and Karsoon, who viewed themselves primarily as fishermen. A third elder, Lapun, is known throughout the island for his knowledge of folklore, and was recommended by the national cultural heritage curator. This elder viewed himself primarily as a gardener.

Each of the three elders was interviewed separately in a local dialect, Pijin, except in the case of the gardener, Karsoon, who felt more comfortable using a mixture of Pijin and a very localised dialect that was quite dissimilar to Pijin. Whenever Pijin was not used a fellow villager served as a translator. During the interview a large gathering of villagers served as an attentive audience.

In order to ensure that the elders perceived the interview process as meaningful, initial questions focussed on the context of their chief occupations, that is, the ocean or land environment. Each elder was asked to explain how they would know when it was the best time for fishing or how they knew when or where they could plant their gardens. The elders were asked for their views on the extent to which schooling helps students to understand better the gardening or fishing process that was practised in their villages. Each of the *elders seemed to be genuinely interested* in participating in the interviews to an extent that, at times, they asked whether they had answered satisfactorily the questions. A local high school principal who was present during the interviews claimed that the elders were frank and candid. Their critical attitudes towards the value of schooling bears testimony to their frankness.

Local Students

Within Kantri, less than 10% of students are given the opportunity to receive further education after completing high school. Consequently, most students return to their villages while the privileged few obtain employment in some of the few towns. The majority of the islands within Kantri have no towns, but each has a small store that sells trade goods such as salt, clothing material, fishing or gardening tools, and fuel. Nevertheless, most students envisage themselves as obtaining well-paid employment when they graduate from high school.

In this study, we interviewed a group of Melanesian students who were attending a local high school on one of the main islands. This particular school was chosen because of its accessibility. Because there are very few high schools in Kantri, each high school contains a student population that is fairly representative of students across the whole country. This school was particularly so as it was a boarding school and housed students from a number of remote and rural villages.

In this school, the science curriculum had been imported directly from a nearby Western country. Its classroom implementation had been observed by the first author during a recent study of South Pacific science teachers (Giddings & Waldrip, 1993). That study reported that, in general, South Pacific science teachers have very didactic approaches to teaching which allow very little variation in approaches to learning science beyond passive reception and rote recall. Evidence from other studies supports our contention that South Pacific teachers implement curricula with very little adaptation to the local cultural contexts (Thaman, 1993).

There are twice as many male students as there are female students in the high schools of Kantri. This is due to the patriarchal nature of the culture that places a high value on school education for male adolescents and a high value on traditional domestic education for female adolescents. In this study, we interviewed 11 male and 4 female students, most of whom were aged in their mid to late teens (see Table 1). Students were interviewed in English by the first author. The interviews were recorded on audio-tape and transcribed for analysis. It was explained that their responses would be treated confidentially and that their identities would remain anonymous. Nevertheless, we soon found that most students could not, or would not, provide traditional explanations of natural phenomena that had been discussed successfully with the village elders. All students, except two, seemed to feel that the village stories were foolish and, when pressed for an explanation of natural phenomena, tended to laugh and claim not to know them.

Table 1
Age and Gender of Interviewed Students

Age of Student	Gender	Number of Students
mid-teens	male	6
mid-teens	female	2
late teens	male	4
late teens	female	2
mature age	male	1

Because this line of questioning proved to be relatively fruitless, we decided to focus on students' explanations of traditional methods of gardening or fishing in which they participated when living in their villages. We asked them for their parents' explanations about gardening or fishing practices and asked how they perceived their parents' explanations. The students were asked about the usefulness of what they learn at school for village life. They were asked how well schooling prepared them for village life. They were asked questions concerning what would happen if they tried to implement what they had learnt at school within their village lifestyles. Finally, they were asked for their opinion as to which type of learning – school subjects or village lore – best prepared them for life in the village.

Revised Research Focus

Our revised research focus sought to establish the extent to which the school view was perceived, in a general sense, as being relevant to important traditional village lifestyle practices. The focus of our study shifted from an examination of the influence of the school view on traditional explanations of natural phenomena to an examination of perceptions of the usefulness of the school view in the context of key aspects of daily life in the village.

Results and Discussion

The study suggested that (1) the process of enculturation into a Western school view involves an implicit devaluation of students' traditional world views which govern their village lifestyles; and (2) a Western school view is of limited viability in relation to traditional values and practices. If the schooling process is not meeting cultural expectations, it is likely that the resultant learning will be less than effective. This may be one factor why constructivism is less than effectively implemented in some classrooms. In this case, it may be of value to negotiate acceptable methods of learning for that classroom. Any introduction of alternative learning methods may need to be carefully crafted and negotiated.

When we designed the study, we were concerned about the role of school science in shaping the future lives of peoples of non-Western cultures. Our experience of living and teaching in largely non-Western countries suggested that science curricula that are imported directly from Western industrialised countries might be less than relevant to the traditional world views held by members of the local culture. We were aware of research that indicated that the cultural background of the non-Western learner has a strong influence on their learning of school science, and we wondered whether the reverse might also be true. That is, we wanted to investigate the extent to which the school view of science permeates the world views of students in non-Western cultures.

We conducted an interpretive-ethnographic study that investigated the relationship between the world view and school view of a group of high school students in one Melanesian culture. In fact, a number of subcultures existed amongst these participants. Even though all were Melanesian, some had a culture that is very similar to Polynesia. Besides sharing some Polynesian cultural expectations, they spoke a Polynesian-based language. They were viewed by the local inhabitants as Melanesian. Other participants had Micronesian cultural linkages. The rest had different ethnic backgrounds. All participants live in the same country and are viewed as Melanesians by the other participants. The students had left temporarily their traditional village lifestyles while they attended a residential high school in a rural area where they were studying a Western-oriented school science curriculum. We were able to gain insights into the traditional world views of villagers by interviewing several respected elders who told stories about their traditional ways of gardening and about their early experiences of Western schooling. We focussed our investigation on the perceived influence of school views on traditional village beliefs and practices.

Because of the limited employment prospects on the island, most students would resume village life on completion of high school. It seemed obvious to us that the science education they were receiving at school should serve an important role in their future lives, whether they sought employment in towns or returned to their villages. We were disappointed to learn, however, that schooling currently disconnects young people from their own cultural beliefs and practices, and attempts to enculturate them into a largely irrelevant

Western school view. At school, a preoccupation with teaching with high fidelity an imported Western-oriented curriculum seems to have blinded teachers to their unwitting promotion of a cultural cringe amongst their students. At school, students embrace the legitimised rationality of school science while developing negative attitudes toward their traditional world views. Back in the village, however, young high school graduates experience difficulties fitting back in to a world view that they have learned to eschew.

Generally speaking, the village elders and high school students whom we interviewed did not perceive the school view as useful for improving the knowledge and skills needed for survival in the village. For example, school science was regarded as providing methods of agriculture that were either inferior to or no better than traditional agricultural practices. Indeed, there was a general perception that the school view conflicted with traditional values and practices, and served to undermine young people's respect for traditional lifestyles. The main perceived benefit of formal education for young people was its improvement of their prospects of earning a monetary income that could be shared with their extended families if they were able to obtain scarce employment in a town.

In this brief study of traditional Melanesian culture, we obtained disturbingly little evidence of the positive influence of the school view of science on young people's traditional world views. We were left with the distinct impression that much of what goes on in the high school science classroom in rural Kantri is of little relevance to the future lives of most young Melanesians. Of course, we did not observe the science classes attended by students in this study and, therefore, cannot judge the extent to which the teachers were attempting to adapt their Western science curricula to local needs. Nevertheless, whatever may be going in these classes (and other research indicates that very little adaptation to local needs is occurring), the outcome is less than impressive from the points of view of local people.

We believe that the educational challenge for developing countries such as Kantri, which currently import science curricula from Western countries, is one of curriculum adaptation to the local culture. This can be achieved only through a rich understanding of the prevailing (albeit changing) cultural values and practices of the local people. Above all else, it is imperative to avoid a neo-colonialist policy that legitimises young people's relinquishment of their cultural heritage in favour of an inappropriate Western scientistic school view that creates a false dawn of expectations for the 'well-qualified' high school graduate. Further research needs to be conducted in Kantri, and in other non-Western cultures, to document the world views of local indigenous people and to suggest ways that the power of Western science may be harnessed in their interests.

This study reversed the focus of a previous study (Baker & Taylor, in press) by examining the prospects of school science making a significant contribution to local cultural practices. Similarly, the discussion presented here reversed the focus of much educational research in non-Western countries which shows how little transference of learning occurs when trying to impose a Western curricula on non-Western countries. This paper seeks to conclude with what can be learnt from a non-Western setting which is applicable to Western high schools which are containing an increasing diversity of different cultures. This study indicates that the need to adapt to local cultural learning practices. It also stressed that much schooling tends to devalue traditional views and consequently schooling can have limited viability in relation to traditional values and practices.

Just as this study had to adapt to the local culture, any study within a typical Australian (or Western) high school needs to address the concerns of multicultural classrooms. This paper supports Cobern's (in press) rejection of cultural deficiency being a major cause of the unsuitability of the adoption of Western learning processes in a non-Western educational system, and argues that understanding the local cultural context is essential in the learning process. True constructivists will not merely look for a technical 'alternative pathway' of learning but rather focus on culturally acceptable learning processes. This paper suggests that teachers need to relate students' learning to meaningful past experiences. Eventually this will involve students' personal constructions. Rather than being an obstacle to learning, we perceive the understanding and effective utilisation of cultural expectations as an essential aspect of the learning process. Even so, as we communicate, we make and remake our own cultures (Bhola, 1990). Hence, involving culture in the learning process is a dynamic, not static process. That is, a constant state of reflection and negotiation is essential for effective learning to occur in Australian multicultural classrooms. Our next line of research plans to examine this interaction of students' perceptions of the learning process and their cultural expectations. It is envisaged that this examination will help teachers to be more aware of the cultural effects in the learning process.

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APPLICATIONS OF THE SCIENCE LABORATORY ENVIRONMENT INVENTORY (SLEI) IN SINGAPORE

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Background

Classroom Environment Research

Although classroom environment research has spanned a period of more than 20 years (Fraser, 1994; Fraser & Walberg, 1991), research specifically in science laboratory classroom environment still is in its infancy. Recently the development of the *Science Laboratory Environment Inventory (SLEI)* (Fraser, Giddings & McRobbie, 1992a; Fraser, McRobbie & Giddings, 1993) has facilitated the expansion of research in this area. It is indeed timely that such an instrument is available for use with science laboratory classes because previous research on science laboratory instruction had focused mainly on comparing one method of laboratory work with another, or with conventional classroom teaching over relatively short periods of time (Hofstein & Lunetta, 1982). DeCarlo and Rubba (1991) also reported that research in this area has not been comprehensive. For example, not enough is known about the effects of laboratory instruction on students' learning and attitudes. Now, with the availability of the SLEI, students' perceptions of laboratory classroom environment can be assessed easily. Information from the SLEI permits science educators and teachers to investigate the impact of laboratory classes on students' outcomes, and can help to guide improvements in laboratory environment settings. This in turn can contribute to the improvement of teaching and learning in science laboratory classes (Hofstein & Lunetta, 1982; Lehman, 1989).

Recent research on laboratory classroom environments using the SLEI in Australia has indicated that the dimensions of the SLEI were related positively with student attitudes (McRobbie & Fraser, 1993). In a previous cross-national study involving six countries, Fraser et al. (1992a) reported similar results. These findings are educationally important because they suggest how to promote positive attitudes among students by creating laboratory environments that stress those areas that have been found empirically to be associated with student attitudes.

In the cross-national study, an examination of sex differences on SLEI scores also was made. Consistent differences between the male and female students' perceptions of their science laboratory classroom environment were found. This finding is also of importance because it suggests how teachers could handle their laboratory procedures more fairly, giving both males and females equal opportunities for participation.

The Singapore Scene

Singapore is an island state with a population of 2.6 million. She has virtually no natural resources except her people. In order for her people to survive and prosper, they must "make themselves relevant to the world and provide services and products which are required by the international community" (Tan, 1990). To achieve this goal, a good education system is needed. That is why the Singapore government has made education one of its top priorities.

The Singapore education system is a highly centralised one. The curriculum to a large extent is prescribed by the Ministry of Education because of the common national examination 'hurdles' that need to be crossed in order to move from the primary school to secondary school (i.e., grade 6 to grade 7), from secondary school to pre-university (i.e., grade 10 to grade 11), and from pre-university to tertiary level (i.e., grade 12 to college).

An important feature in the Singapore education system is that Science is a compulsory subject in the primary and secondary school curriculum. This has been especially important since she moved from a labour-intensive economy to a highly technological one. Research into science education is thus important as it provides vital information to science educators at all levels as to how science education can be further improved for the betterment of the learners and in turn for the society as a whole.

A review of the science education research in Singapore (Toh, 1993) revealed that no study specifically of science laboratory classroom environments has been reported previously. Thus, this study of chemistry classes is an attempt to mark the beginning of this field of research in science education in Singapore. It is felt that findings from studies such as this not only would complement the work already done and still being done, but would provide a more complete picture of the process of science education existing in Singapore.

Objectives of the Paper

This paper reports some findings from a larger study on the determinants and effects of science laboartory classroom environments conducted in Singapore (Wong, 1994), particularly, the differences in actual and preferred perceptions of chemistry laboratory classroom environments between teachers and students, and male and female students.

The Chemistry Laboratory Environment Inventory (CLEI)

The chemistry laboratory classroom environment perceptions of the students and the teachers were assessed using the *Chemistry Laboratory Environment Inventory (CLEI)*. It is a modified version of the Science Laboratory Environment Inventory (SLEI) mentioned earlier in this paper. The modification of the instrument only entailed replacing the word 'science' with 'chemistry' throughout. The rest of the wording of items remained unchanged.

The original SLEI comes in two forms, the Class form and the Personal form. The Class form assesses the students' perceptions of the class as a whole, while the Personal form assesses the students' perception of his/her own role in the laboratory class. Each of these forms comes in two versions – the actual and the preferred. Hence, the students' perceptions of both their actual and ideal (preferred) learning environments can be assessed.

In the Singapore study, students' and teachers' perceptions of the chemistry laboratory environment was measured using the actual and preferred versions of the Personal form and Class form of the SLEI, respectively (renamed the Student form and the Teacher form of the CLEI, respectively). The Personal form was chosen for the students because it was felt that it would be more sensitive in assessing the differences between subgroups within a class (e.g., males and females) (Fraser & Tobin, 1991), which was one of the areas being investigated in this study.

As in the SLEI, the original CLEI used in this study consisted of 35 items, with seven items in each of the five scales: Student Cohesiveness, Open-Endedness, Integration, Rule Clarity and Material Environment. Items are arranged in a cyclic order and 13 of them are worded and scored in the reverse manner. However, following the item analysis (refer to Wong, 1994) two items were deleted to form a final form of the CLEI containing 33 items altogether. A five-point scale, with the alternatives of Almost Never, Seldom, Sometimes, Often and Very Often, is used for the responses.

Sample

The sample consisted of 1,592 final year secondary school (i.e., tenth grade) chemistry students (763 males and 829 females) and their chemistry teachers in 56 intact classes from 28 randomly selected coeducational government schools of similar standard in Singapore. The teacher data comprised 56 sets of responses to the questionnaires, one for each of the 56 clases which took part in the study.

The students and teachers completed the actual and preferred versions of the Student form and the Teacher form of the CLEI, respectively. Approximately one hour was required to administer all questionnaires to each class.

Results

Comparison of Sudents' and Teachers' Perceptions

The actual and preferred perceptions of the chemistry laboratory classroom environment of students and teachers were measured using the CLEI. The CLEI data for the 56 classes were used to generate four sets of environment perceptions scores for each class on each of the five CLEI scales: the class mean of students' actual scores; the class mean of students' preferred scores; the teacher's actual score; and the teacher's preferred score. The means of each set of perception scores (the scale means) calculated across the 56 classes are tabulated in Table 1.

Table 1

Scale Means and Standard Deviations for Actual and Preferred Versions of the CLEI for Students and Teachers

			Scale Mean		Standard Deviation			Item Mean[a]	
Scale	No. of Items	Form	Student	Teacher	Student Individual	Student Class Mean	Teacher Individual	Student	Teacher
Student Cohesiveness	7	Actual	26.96	26.88	4.12	1.28	3.36	3.85	3.84
		Preferred	28.38	30.38	4.24	1.39	3.21	4.05	4.34
Open-Endedness	6	Actual	14.04	11.66	3.08	0.86	3.30	2.34	1.94
		Preferred	17.15	18.36	4.30	1.33	3.75	2.86	3.06
Integration	7	Actual	27.26	27.45	4.05	1.58	5.42	3.89	3.92
		Preferred	27.70	30.43	4.47	1.57	3.11	3.96	4.35
Rule Clarity	6	Actual	22.99	25.79	3.54	1.43	2.90	3.83	4.30
		Preferred	23.42	26.54	3.59	1.26	2.72	3.90	4.42
Material Environment	7	Actual	24.55	25.73	4.81	1.95	4.39	3.51	3.68
		Preferred	28.47	32.27	5.40	2.21	3.38	4.07	4.61

Note. The student sample consisted of 1,592 upper secondary chemistry students in 56 classes. The teacher sample comprised 56 sets of teacher responses, one for each of the 56 classes.

[a] The Item Mean was calculated by dividing the scale mean by the number of items in that scale. All the scales have 7 items each, except Open-Endedness and Rule Clarity which have 6 items each.

In Table 1, Student Cohesiveness, Integration and Material Environment each contain seven items while Open-Endedness and Rule Clarity each contains six items. Because of this difference in the number of items in the five scales, the item mean (i.e., the scale mean divided by the number of items in the scale) for each scale was calculated so that there is a fair basis for comparison between different scales. The item mean for each scale are given in the last two columns of Table 1.

The first step in the construction of the classroom environment profiles shown in Figure 1 for each CLEI scale involved the performance of a one-way multivariate analysis of variance (MANOVA) with repeated measures. For these analyses, the 'form' of the instrument (e.g., student/actual) constituted a four-level repeated measures factor, while the set of five CLEI scales constituted the dependent variables. Because Wilks' lambda criterion was statistically significant ($p<0.01$), a univariate one-way analysis of variance (ANOVA) for repeated measures was examined for each of the five scales individually. Finally, in cases for which the ANOVA yielded statistically significant results, pair-wise comparisons between different forms of the same scale (e.g., student/actual versus student/preferred) were performed using *t*-tests for dependent samples. This three-step approach for the analysis was taken so as to reduce the Type I error rate associated with the performance of multiple *t*-tests.

The item means shown in Table 1 for each scale in the actual and preferred version of both the Student and Teacher forms of the CLEI were plotted in Figure 1. In an attempt to provide a more parsimonious picture of the differences between scores on pairs of forms of each CLEI scale, only the item means which were found to be significantly different ($p<0.05$) found in the MANOVA were plotted. Any nonsignificant difference between a pair of forms for a particular scale was represented as a zero difference by averaging the relevant pair of item mean scores. The response alternatives of the CLEI instrument corresponding to the value intervals on the item mean axis in Figure 1 are as follows: 1='Never', 2='Seldom', 3='Sometimes', 4='Often', and 5='Very Often'.

Figure 1: Simplified Plot of Significant Differences between Student (Actual), Student (Preferred), Teacher (Actual) and Teacher (Preferred) Perception Scores

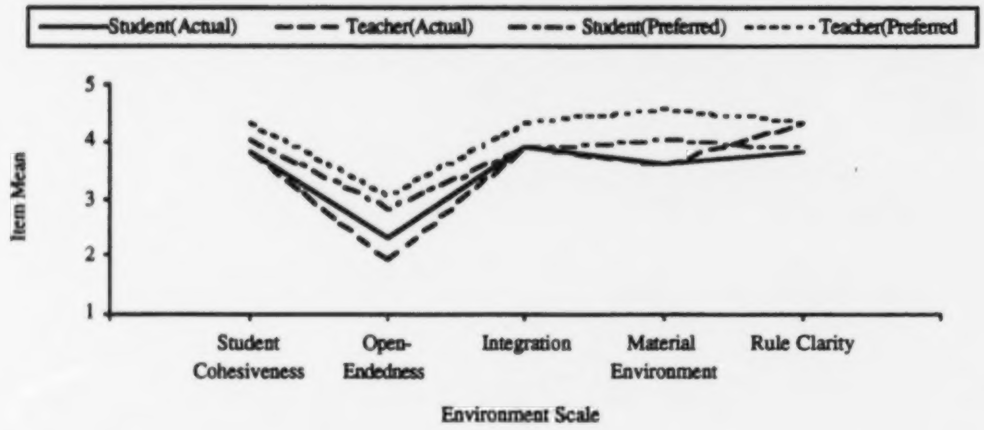


Figure 1 shows that teachers and students tended to have similar perceptions of the levels of Student Cohesiveness, Integration and Material Environment existing in their classes. However, teachers perceived a significantly lower occurrence of Open-Endedness but a higher level of Rule Clarity than their students. For the preferred perceptions, both teachers and students prefer an environment with greater levels of Student Cohesiveness, Open-Endedness and Material Environment. Students also preferred more Rule Clarity while teachers preferred more Integration instead. In general, teachers' perceptions were either similar to or more positive than those of their students on most of the CLEI dimensions. This finding replicated previous classroom environment research to some extent (Moos, 1979; Fraser, 1982).

Comparison of Male and Female Students' Perceptions

The perceptions of male and female students also were compared in the Singapore study. The first step in the analysis involved a two-way multivariate analysis of variance (MANOVA) with repeated measures on one factor performed for the set of 10 environment scales (five actual and five preferred) as dependent variables. One independent variable was the stream (this variable is not discussed in this paper) and the repeated measures independent variable was sex. This analysis confirmed that significant differences existed overall between the sexes and between streams. It also showed that there was no significant interaction between sex and stream. This justified an examination of the results of a two-way univariate analysis of variance (ANOVA) for each of the 10 CLEI scales separately. This two-step approach for the analysis was taken so as to help reduce the Type I error rate which may arise from numerous individual significance tests. The scale means for the actual and preferred perception scores calculated across the 50 coeducational classes for each of the five CLEI scales are tabulated in Table 2. As in the case for Table 1, item mean for each scale was also calculated and reported in the last two columns of Table 2.

Table 2

Scale Means and Standard Deviations for the Actual and Preferred Versions of the CLEI for Male and Female Students

Scale	No. of Items	Form	Scale Mean			Standard Deviation		Item Mean[a]	
			Male	Female	Difference	Male	Female	Male	Female
Student Cohesiveness	7	Actual	26.87	27.15	0.28	1.69	1.45	3.84	3.88
		Preferred	28.14	28.70	- 0.56*	1.82	1.42	4.02	4.10
Open-Endedness	6	Actual	14.25	13.73	0.52**	1.05	1.08	2.38	2.29
		Preferred	17.50	16.83	0.67*	1.89	1.54	2.92	2.81
Integration	7	Actual	27.01	27.77	- 0.76**	1.70	1.64	3.87	3.97
		Preferred	27.27	28.28	- 1.01**	1.95	1.72	3.90	4.04
Rule Clarity	6	Actual	26.27	26.48	- 0.21	1.50	1.76	4.38	4.41
		Preferred	26.36	27.19	- 0.83**	1.65	1.54	4.39	4.53
Material Environment	7	Actual	24.47	24.95	- 0.48	2.43	2.10	3.50	3.56
		Preferred	27.85	29.30	- 1.45**	2.94	2.15	3.98	4.19

Note. The sample size was 1,450 students from 50 coeducational classes in 28 schools. Of these, there were 649 male students and 801 female students. The six single-sex classes were omitted when generating the statistics for this table.

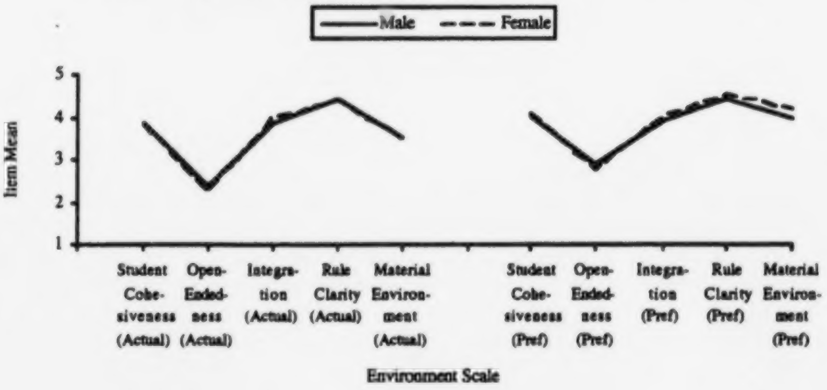
[a] The Item Mean was calculated by dividing the scale mean by the number of items in that scale. All the scales have 7 items each, except Open-Endedness and Rule Clarity which have 6 items each.

* $p<0.05$

** $p<0.01$

As in the case of Figure 1, only the significant score differences ($p<0.05$) were plotted in Figure 2. The response alternatives corresponding to the value intervals on the item mean axis in Figure 2 are the same as those for Figure 1.

Figure 2: Simplified Plot of Significant Differences between Male and Female Actual and Preferred Perception Scores



An examination of Table 2 and Figure 2 shows that male and female students differed significantly ($p<0.01$) in their actual perceptions for two of the five CLEI scales, namely, Integration and Open-Endedness. Female students perceived that Integration was practised more frequently and Open-Endedness less frequently than was perceived by their male counterparts. Each of these differences had an effect size of about 0.50 standard deviations. There was no significant difference between perceptions for the remaining three scales.

Figure 2 shows that the differences in preferred perception scores between male and female students differed significantly ($p<0.05$) for all five CLEI scales. Female students had higher levels of preferences than the male students in four of the five CLEI scales, namely, Student Cohesiveness, Integration, Rule Clarity and Material Environment. These differences amounted to effect sizes ranging from 0.35 to 0.60, all in favour of the female students. However, in the area of Open-Endedness, an effect size of 0.39 in favour of the male students was found.

Overall the Singapore results for sex differences partially replicate previous research which has shown that female students tend to have a more favourable perception of their classroom environments than their male counterparts (Lawrenz, 1987; Giddings & Fraser, 1990; Fraser et al., 1992b).

Conclusion

The Science Laboratory Environment Inventory (SLEI) is a fairly new instrument for assessing perceptions of science laboratory classroom environments (Fraser et al., 1992a). For the Singapore study, it was modified, renamed the Chemistry Laboratory Environment Inventory (CLEI), and administered to 1,592 secondary school students and their chemistry teachers to assess their perceptions of the chemistry laboratory classroom environments. A description of the SLEI and the findings on the comparison of actual and preferred perceptions of teachers and students, and of male and female students were discussed in this paper.

When the perceptions of teachers and students were compared, it was found that teachers' perceptions were generally similar or more positive than those of their students on most of the CLEI dimensions. Also, preferred perceptions of both teachers and students were more favourable than their actual perceptions. These findings were consistent with those reported for other classroom environment instruments in past research (e.g., Moos, 1979; Fraser, 1982).

The Singapore study also reported that male and female students differed in their actual perceptions of Integration and Open-Endedness, and in their preferred perceptions for all five CLEI scales. In most of these cases, female students were found to hold more favourable perceptions than male students, as was reported in previous research (Lawrenz, 1987; Giddings & Fraser, 1990; Fraser et al., 1992b). However, unlike previous research, males in the present study perceived Open-Endedness more positively than the females.

It is hoped that these findings from the Singapore study will help substantiate past research involving the SLEI and add to its data set, thus enhancing its useability across nations, cultures and educational settings.

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